DC-P-1060-1

PREDICTION OF URBAN CASUALTIES AND THE MEDICAL LOAD FROM A HIGH-YIELD NUCLEAR BURST

L. Wayne Davis

Paper
prepared under

Contract No. N0022867C2276
(Work Unit No. 2411H)

Sponsored by

Office of Civil Defense
Office of the Secretary of the Army

through

Technical Management Office
U. S. Naval Radiological Defense Laboratory

Delivered at

Workshop on Mass Burns
National Academy of Sciences
Washington, D. C.
March 13-14, 1968

The Dikewood Corporation
1009 Bradbury Drive, S. E.
University Research Park
Albuquerque, New Mexico 87106

II. CASUALTY CURVES FOR PERSONS IN OR SHIELDED BY STRUCTURES

A. DEVELOPMENT OF "BLAST" MORTALITY CURVES FROM JAPANESE AND TEXAS CITY DATA

A great deal of new information has been gathered concerning the biological effects of the nuclear attacks on Hiroshima and Nagasaki, Japan, during World War II. The data from over 35,000 case histories were collected on magnetic tape, and the results of the analysis were published in DC-FR-1054 (Ref. 3).

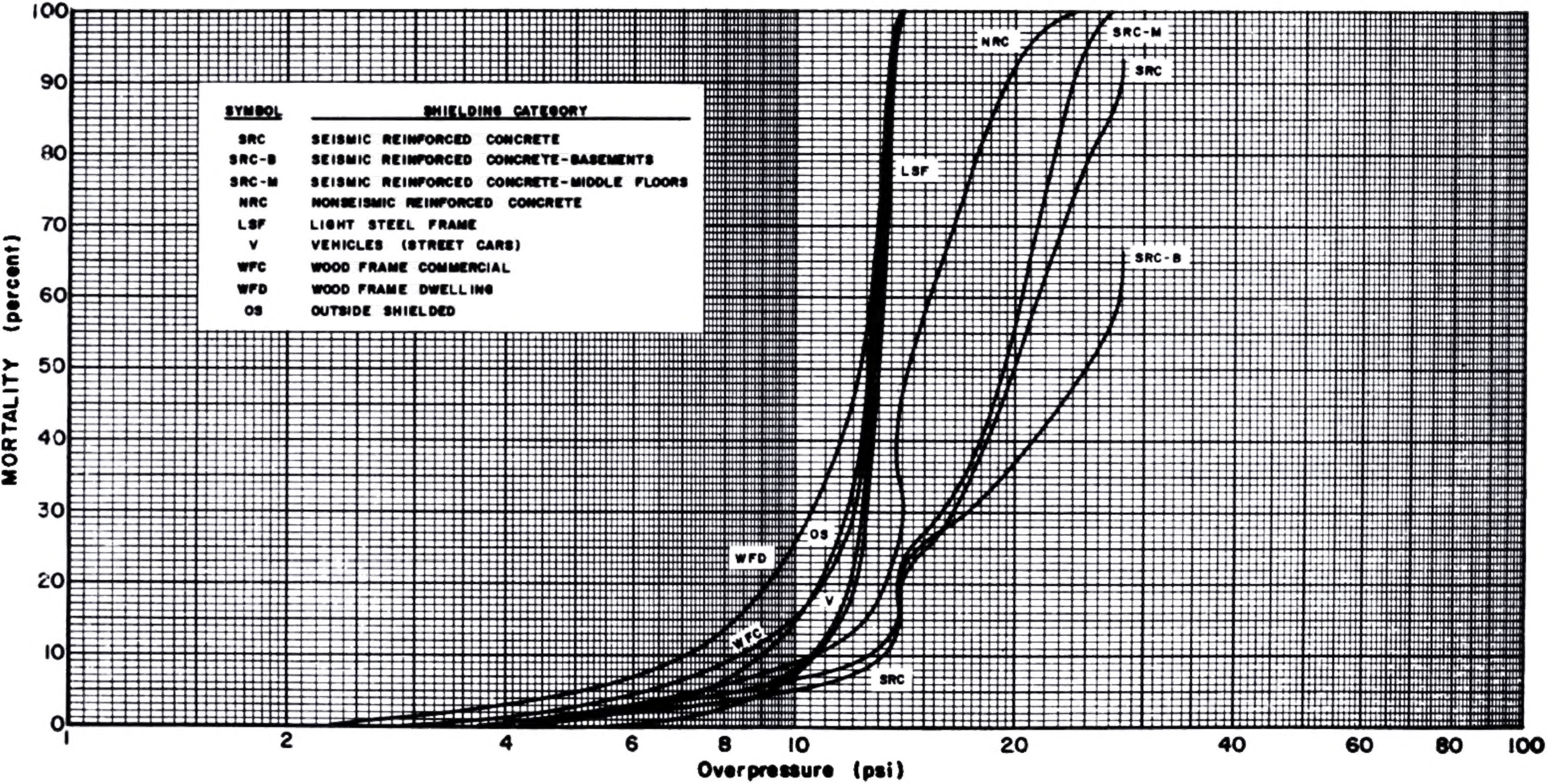
The Japanese mortality curves for people in or shielded by structures are plotted as a function of overpressure in Figs. 1 and 2 for Hiroshima and Nagasaki, respectively. These curves are based on a yield for Hiroshima of 12.5 kt burst at a height of 1870 feet (scaled height of 806 feet) and a yield for Nagasaki of 22 kt burst at a height of 1640 feet (scaled height of 585 feet).

The mortality curves from the Texas City disaster of 1947, separated by shielding category, are given as a function of overpressure in Fig. 3. This surface burst* has been estimated to be equivalent to a nuclear yield of 0.67 kt.

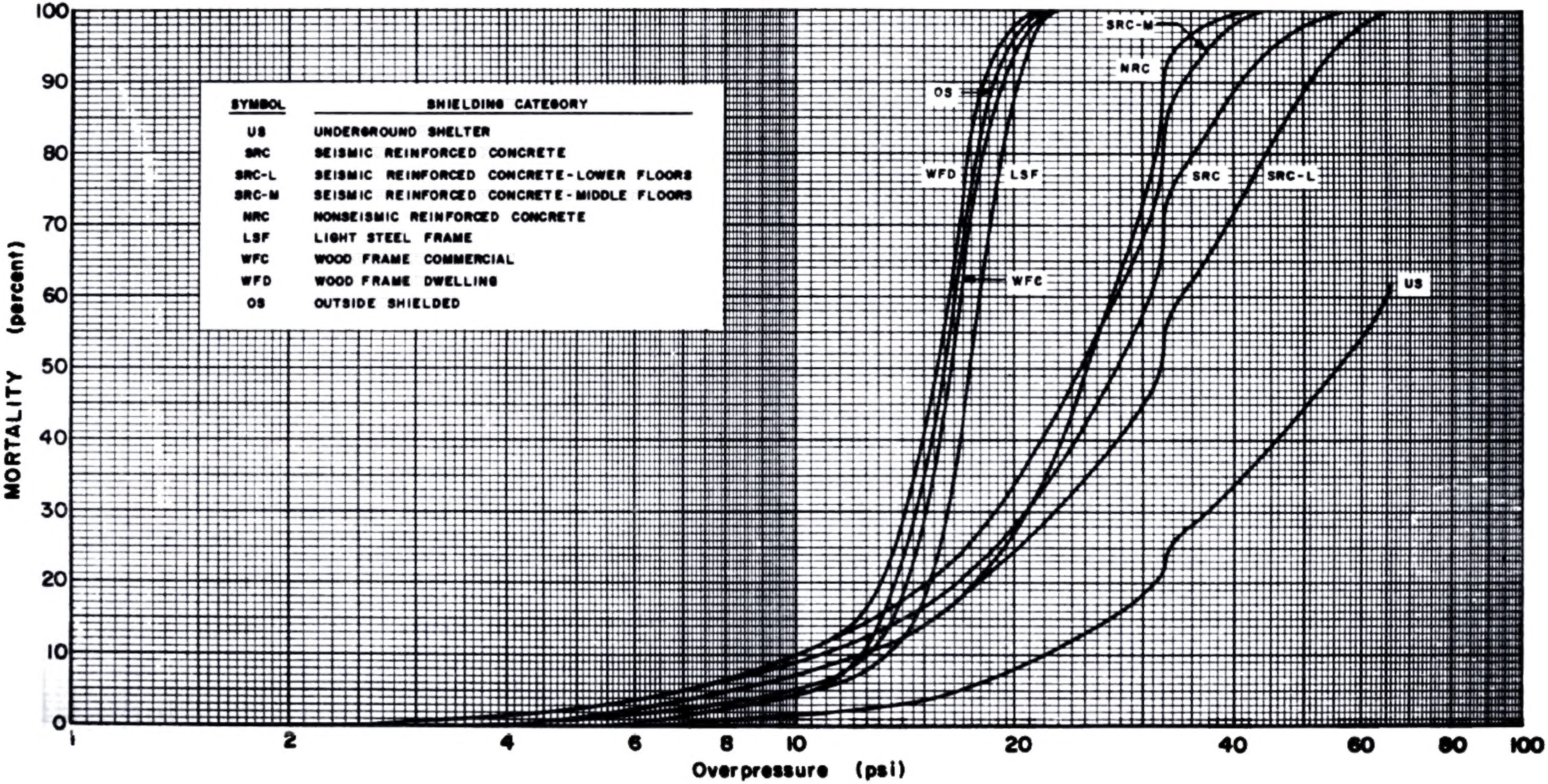
The next step was to develop a set of "blast" mortality curves for a reference 12.5-kt surface burst. Of course, the ultimate goal was

*Ammonium-nitrate fertilizer exploded within the hold of a ship which was tied up at a pier.

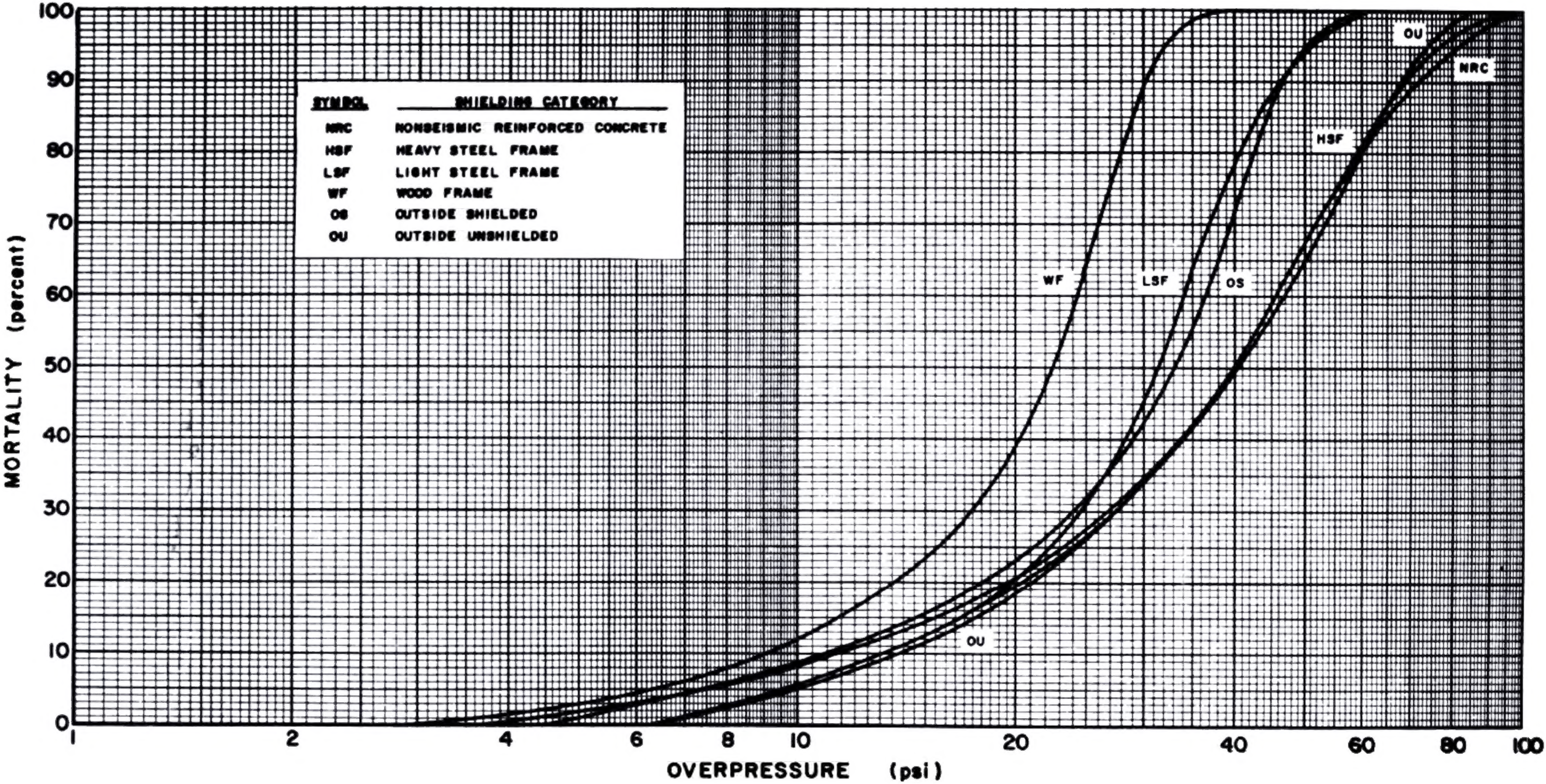
TOTAL MORTALITY CURVES FOR HIROSHIMA



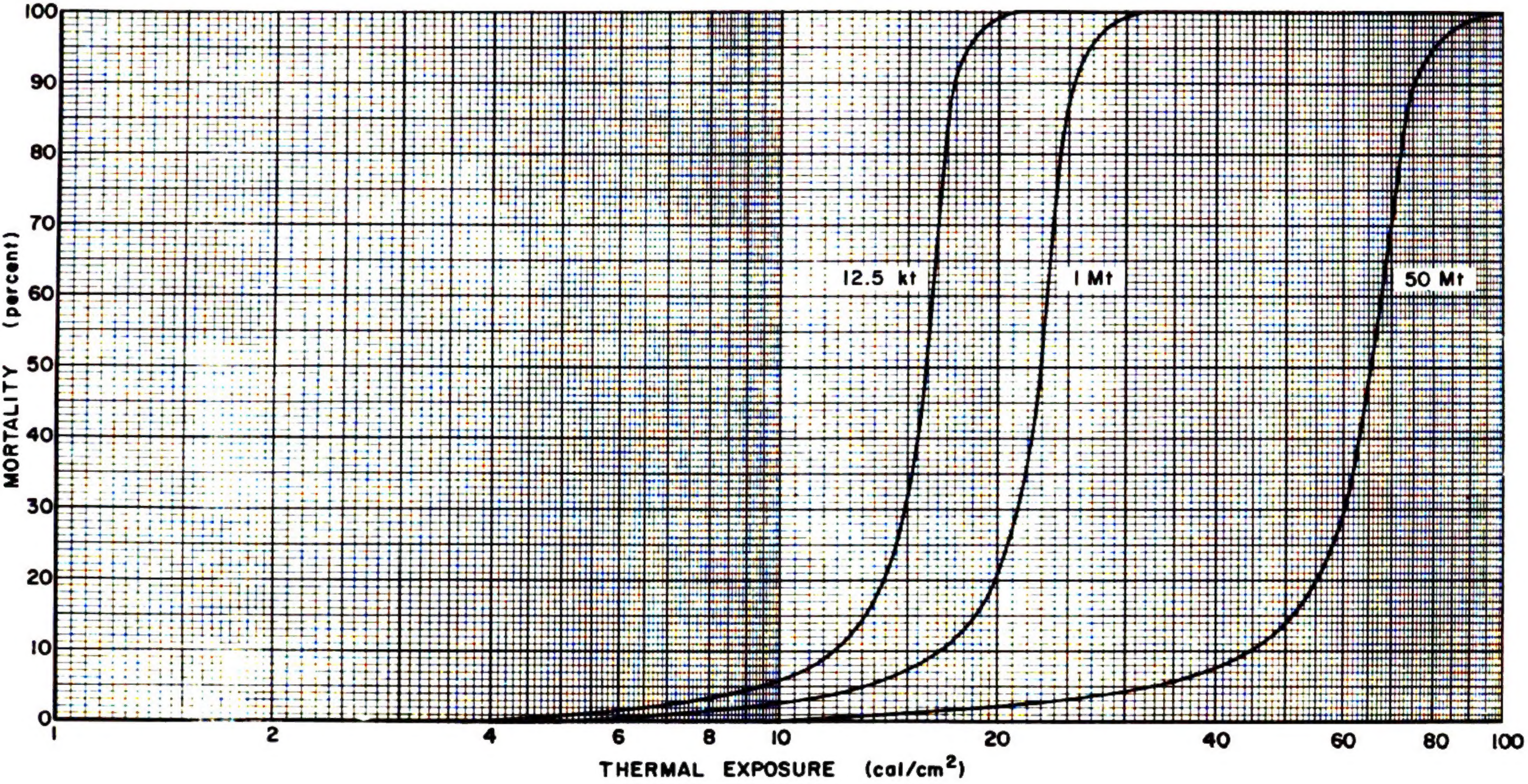
TOTAL MORTALITY CURVES FOR NAGASAKI



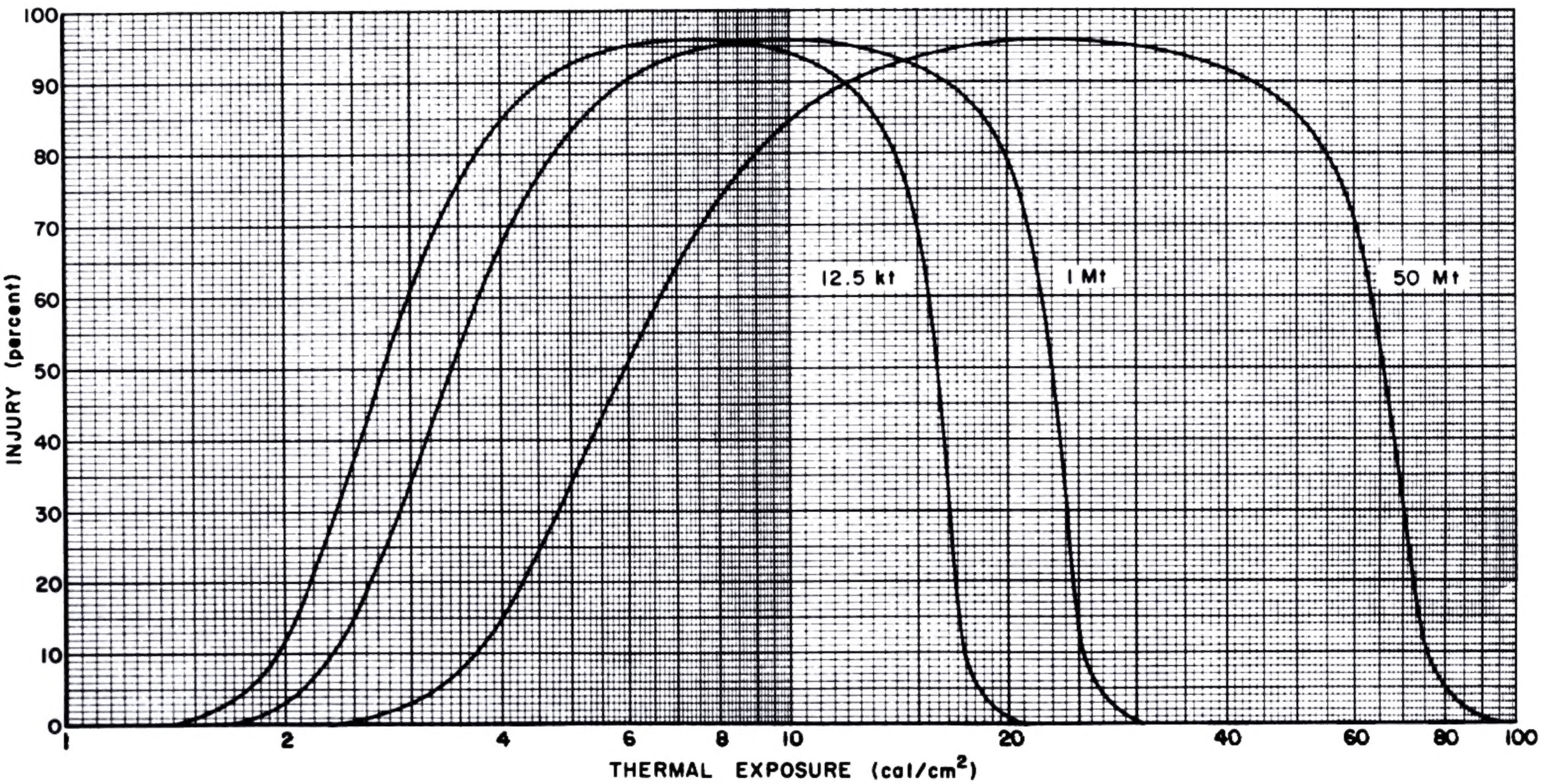
TOTAL MORTALITY CURVES FOR TEXAS CITY



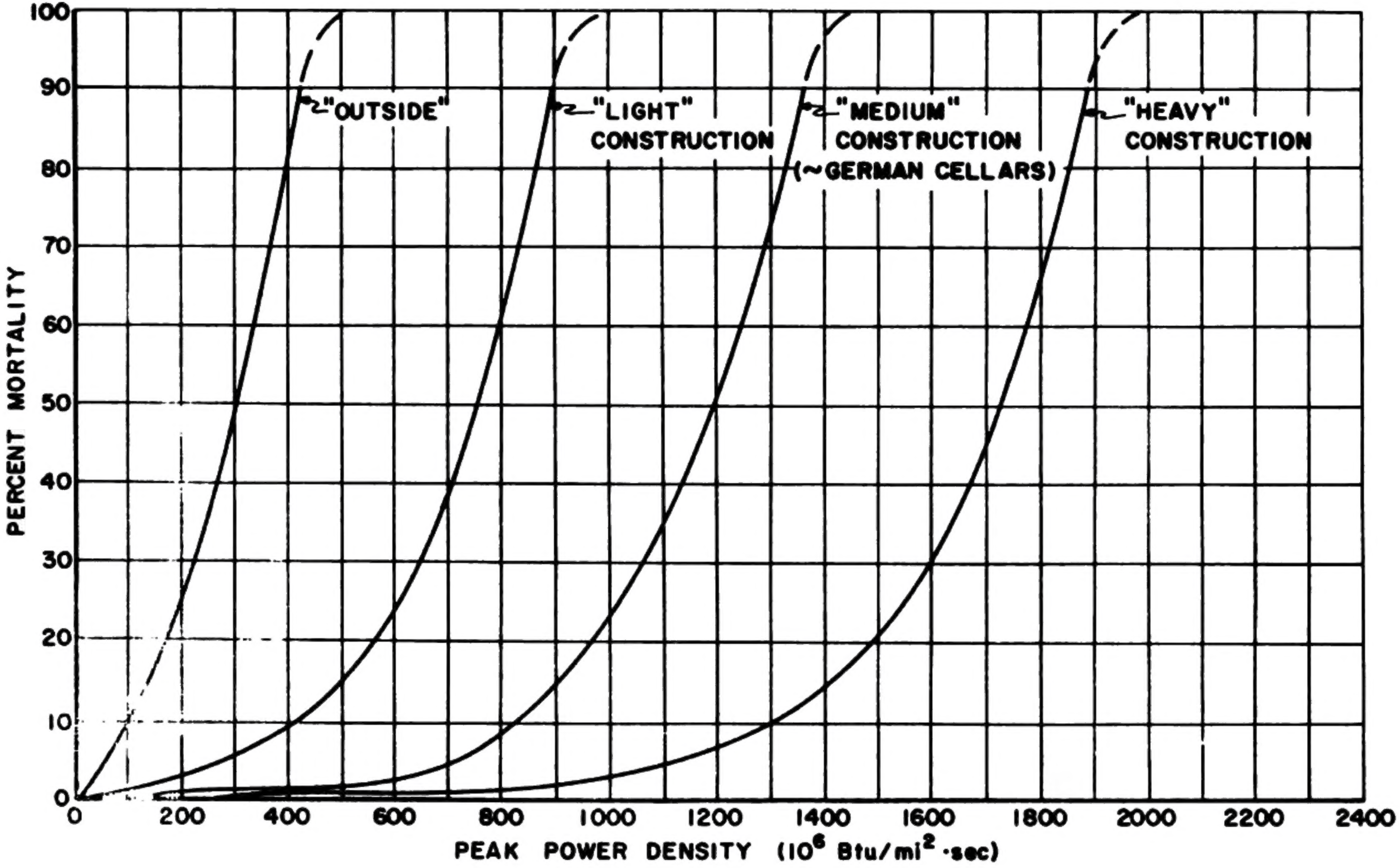
PROMPT-THERMAL MORTALITY CURVES FROM SURFACE BURSTS
FOR OUTSIDE-UNSHIELDED PERSONS



PROMPT-THERMAL INJURY CURVES FROM SURFACE BURSTS FOR OUTSIDE-UNSHIELDED PERSONS



FIRE MORTALITY CURVES



condition for development of firestorms. High ambient winds usually cause conflagrations to develop, as noted above.

B. FIRE MORTALITY CURVES

Fires in nine German cities were analyzed in detail to provide data for the development of fire mortality curves. Similar procedures were applied to the fires caused by the nuclear detonation over Hiroshima. Earlier work in this area indicated a correlation between the peak power density (maximum rate of energy release per unit area of the fire bed) and the percent fire mortality for the population at hazard within the fire area.* The four general groupings of construction or shielding categories given by the curves in Fig. 30 are the result of investigating this correlation (Refs. 14 through 18). The general groupings and breakdowns by shielding category are given below:

1) Heavy Construction
   a) Seismic Reinforced-Concrete Buildings
   b) Nonseismic Reinforced-Concrete Buildings (Basements)

2) Medium Construction
   a) Nonseismic Reinforced-Concrete Buildings (Above Ground)
   b) Heavy Steel-Frame Buildings (Basements)†
   c) Light Steel-Frame Buildings (Basements)†
   d) Heavy Brick Wall-Bearing Buildings (Basements)†

---

*For application of an earlier form of these relationships to historical cases, see Ref. 13.

†If basements are unavailable, this mortality curve probably lies midway between those for medium and light construction.

3) Light Construction
   a) Brick Residential Buildings
   b) Wood-Frame Buildings (Basements)*

4) Outside
   a) Outside-Shielded Category
   b) Outside-Unshielded Category

Two restrictions must be placed on the use of these curves. First, because of the nature of the data available for analysis, the minimum burning area which was analyzed was approximately 20 acres. Consequently, these curves should not be applied to population groups situated in fire environments covering less than 20 acres. Secondly, the shelter postures inherent in the basic German data do not correspond directly to any NFSS or structural shielding categories; therefore, significant variation from the values shown could occur. The curves shown in Fig. 30 are therefore "best estimates."

Computation of the peak power densities (in $\mathrm{Btu/mi^2 \cdot sec}$) required to apply the fire mortality curves is described in DC-FR-1060 (Ref. 4).

C. FIRE INJURIES

This work is still in process, but it is expected that the results will also be presented as a function of the peak power density. The fire injury model will be applied at this point, in parallel with the fire mortality

---

*If basements are unavailable, this mortality curve probably lies midway between those for light construction and the outside category.

LIST OF REFERENCES

1. L. Wayne Davis, Donald L. Summers, Milton E. Jenkins, Francis J. Wall, and William L. Baker, Prediction of Urban Casualties from the Immediate Effects of a Nuclear Attack, DC-FR-1028, The Dikewood Corporation; April, 1963. (Classified)

2. L. Wayne Davis, Francis J. Wall, and Donald L. Summers, Development of "Typical" Urban Areas and Associated Casualty Curves, DC-FR-1041, The Dikewood Corporation; April, 1965.

3. L. Wayne Davis, William L. Baker, and Donald L. Summers, Analysis of Japanese Nuclear Casualty Data, DC-FR-1054, The Dikewood Corporation; April, 1966.

4. L. Wayne Davis, Donald L. Summers, William L. Baker, and James A. Keller, Prediction of Urban Casualties and the Medical Load from a High-Yield Nuclear Burst, DC-FR-1060, The Dikewood Corporation; to be published. (Classified)

5. Ashley W. Oughterson, et al., Medical Effects of Atomic Bombs, NP-3036 to NP-3041 (Vols. I-VI), Army Institute of Pathology; 1951.

6. The Effects of the Atomic Bomb on Hiroshima, Japan, Report No. 92 (Vols. I-III), U.S. Strategic Bombing Survey, Physical Damage Division; May, 1947.

7. Effects of the Atomic Bomb on Nagasaki, Japan, Report No. 93 (Vols. I-III), U.S. Strategic Bombing Survey, Physical Damage Division; June, 1947.

8. J. Rotz, et al., Effects of Fire on Structural Debris Produced by Nuclear Blast, URS 639-9, URS Corporation; January, 1965.

9. Willard L. Derksen, et al., Output Intensities and Thermal Radiation Skin Injury for Civil Defense Shelter Evaluation, Special Report for Blast and Thermal Subcommittee of the National Academy of Science, U.S. Naval Applied Science Laboratory; October 16, 1967.

10. Samuel Glasstone (Editor), The Effects of Nuclear Weapons, U.S. Atomic Energy Commission; 1957 and 1962.

11. J. Bracciaventi, W. Derksen, et al., Radiant Exposures for Ignition of Tinder by Thermal Radiation from Nuclear Weapons, Final Report on DASA Subtask 12.009, U.S. Naval Applied Science Laboratory; July 5, 1966.

LIST OF REFERENCES (Continued)

12. S. B. Martin and N. J. Alvares, Ignition Thresholds for Large-Yield Nuclear Weapons, USNRDL-TR-1007, U. S. Naval Radiological Defense Laboratory; April 11, 1966.

13. T. E. Lommasson and J. A. Keller, A Macroscopic View of Fire Phenomenology and Mortality Prediction, Proceedings of the Tripartite Technical Cooperation Program, Mass Fire Research Symposium of the Defense Atomic Support Agency, The Dikewood Corporation; October, 1967.

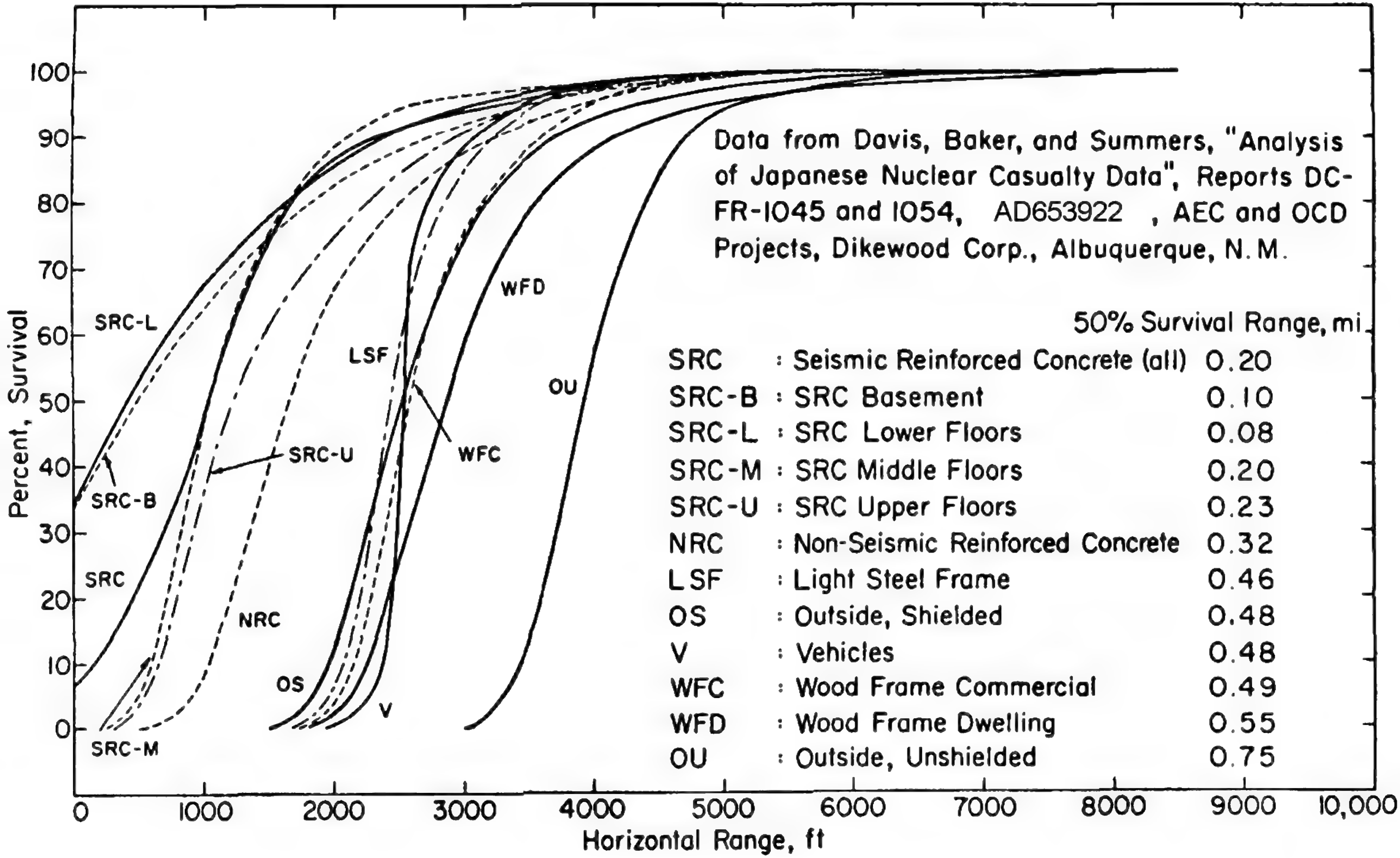
14. J. A. Keller, A Study of World War II German Fire Fatalities, DC-TN-1050-3, The Dikewood Corporation; April, 1966.

15. R. Schubert, Examination of Building Density and Fire Loading in the Districts Eimsbuettel and Hammerbrook of the City of Hamburg in the Year 1943 (20 volumes, in German), Stanford Research Institute; January, 1966.

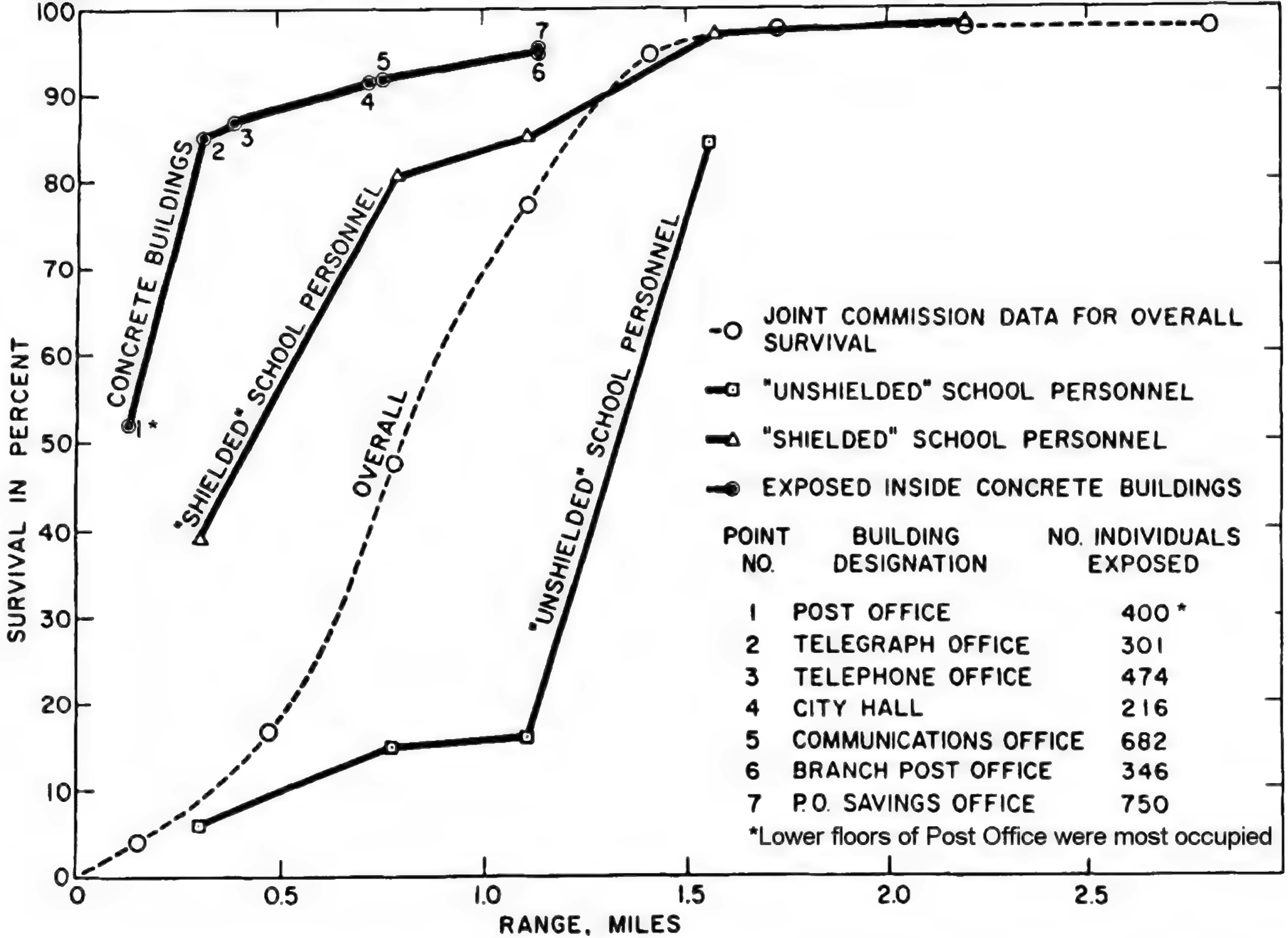
16. G. H. Tryon (Editor), Fire Protection Handbook, Twelfth Edition, National Fire Protection Association, Boston; 1962.

17. C. C. Chandler, T. Storey, and C. Tangren, Prediction of Fire Spread Following Nuclear Explosions, PSW-5, U. S. Forest Service, Forest and Range Experiment Station, Berkeley, California; 1963.

18. Kathleen F. Earp, Deaths from Fire in Large-Scale Air Attack, with Special Reference to the Hamburg Firestorm, CD/SA 28, Home Office, Scientific Advisers' Branch, London; April, 1953.



Percentage of Hiroshima survivors as functions of range and exposure conditions.



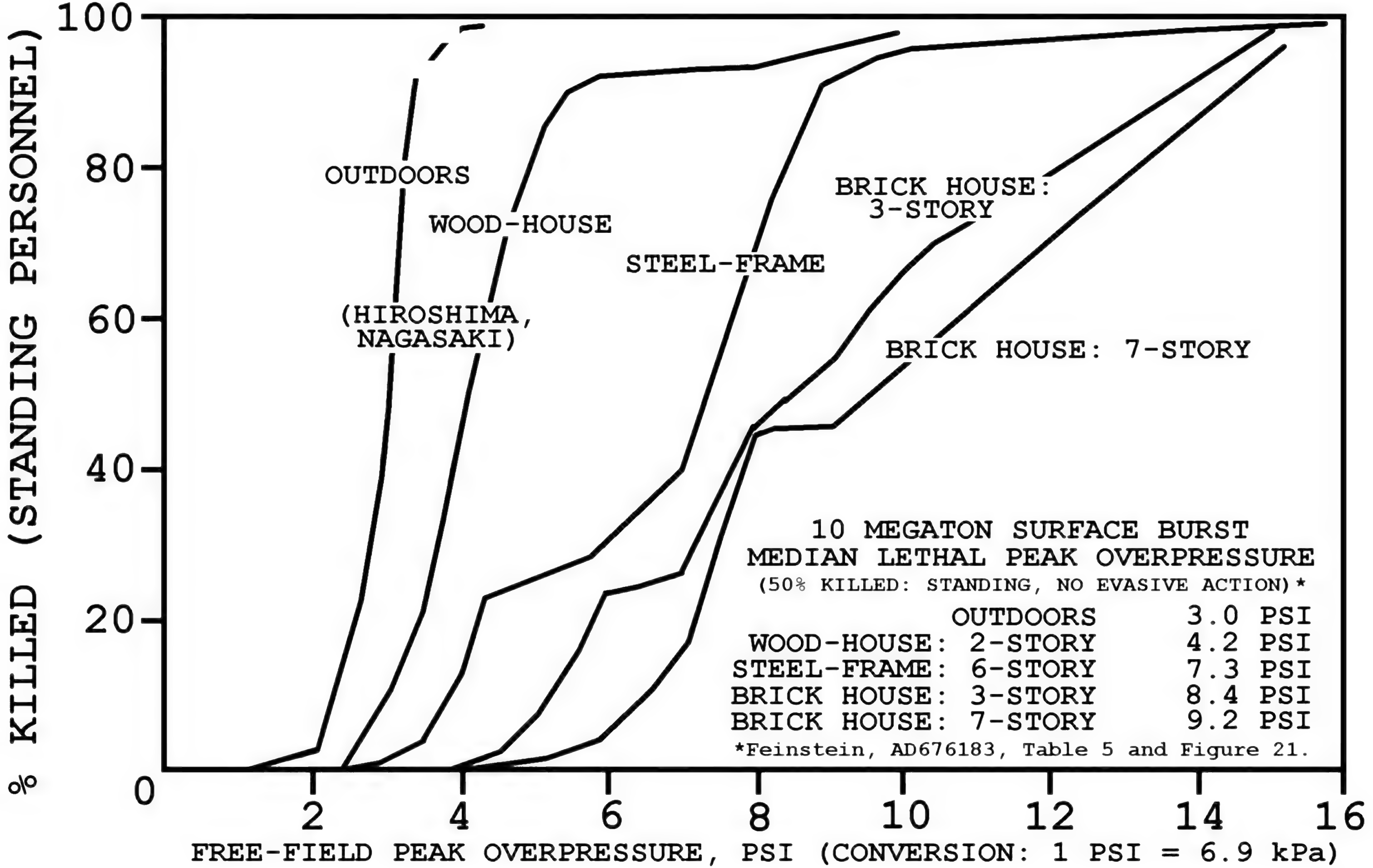
Percentage of survivors as a function of range from Ground Zero (Hiroshima). (Ref. Joint Commission Report, Vol. VI, Document NP-3041.)

FIFTY-PER CENT SURVIVAL CONDITIONS FOR HIROSHIMA

LOCATION	HORIZONTAL RANGE mi	HORIZONTAL RANGE ft	MAX OVER-PRESSURE ENW psi	THERMAL RADIATION ENW cal/cm^2
SRC, SEISMIC REINFORCED CONCRETE (ALL)	.20	1,056	19.8	67
SRC, BASEMENT	.10	528	25.6	80
SRC, LOWER FLOORS	.08	422	26.4	83
SRC, MIDDLE FLOORS	.20	1,056	19.8	67
SRC, UPPER FLOORS	.23	1,214	18.0	63
NON-SEISMIC REINFORCED CONCRETE	.32	1,690	14.0	49
LIGHT STEEL FRAME	.46	2,429	13.3	32
OUTSIDE SHIELDED	.48	2,534	13.2	30
VEHICLES	.48	2,534	13.2	30
WOOD FRAME COMMERCIAL	.49	2,587	13.1	29
WOOD FRAME DWELLING	.55	2,904	12.0	25
OUTSIDE UNSHIELDED	.75	3,960	7.9	15

FLASH BURNS AND IMPACTS (NO "DUCK AND COVER" EVASIVE ACTION)

SOURCE: David I. Feinstein, "Casualty Prediction Comparisons", IIT report AD676183, 1968, 10 Mt surface burst: Figs. 1, 6, 11, 16 and 21, and Table 5



DC-FR-1054

ANALYSIS OF JAPANESE NUCLEAR CASUALTY DATA

L. Wayne Davis
William L. Baker
Donald L. Summers

Final Report
on
Contract Nos. OCD-PS-64-196 and N228-(62479)69778
(Work Unit No. 3411A)

Sponsored by

OFFICE OF CIVIL DEFENSE
OFFICE OF THE SECRETARY OF THE ARMY

through

TECHNICAL MANAGEMENT OFFICE
U. S. NAVAL RADIOLOGICAL DEFENSE LABORATORY

April, 1966

THE Dikewood CORPORATION

USNRDL-TRC-46

1009 BRADBURY DRIVE, S.E. / TELEPHONE (505) 243-9781
UNIVERSITY RESEARCH PARK
ALBUQUERQUE, NEW MEXICO 87106

FIG. 27

OUTSIDE-UNSHIELDED BURNS BY DEGREE FOR HIROSHIMA

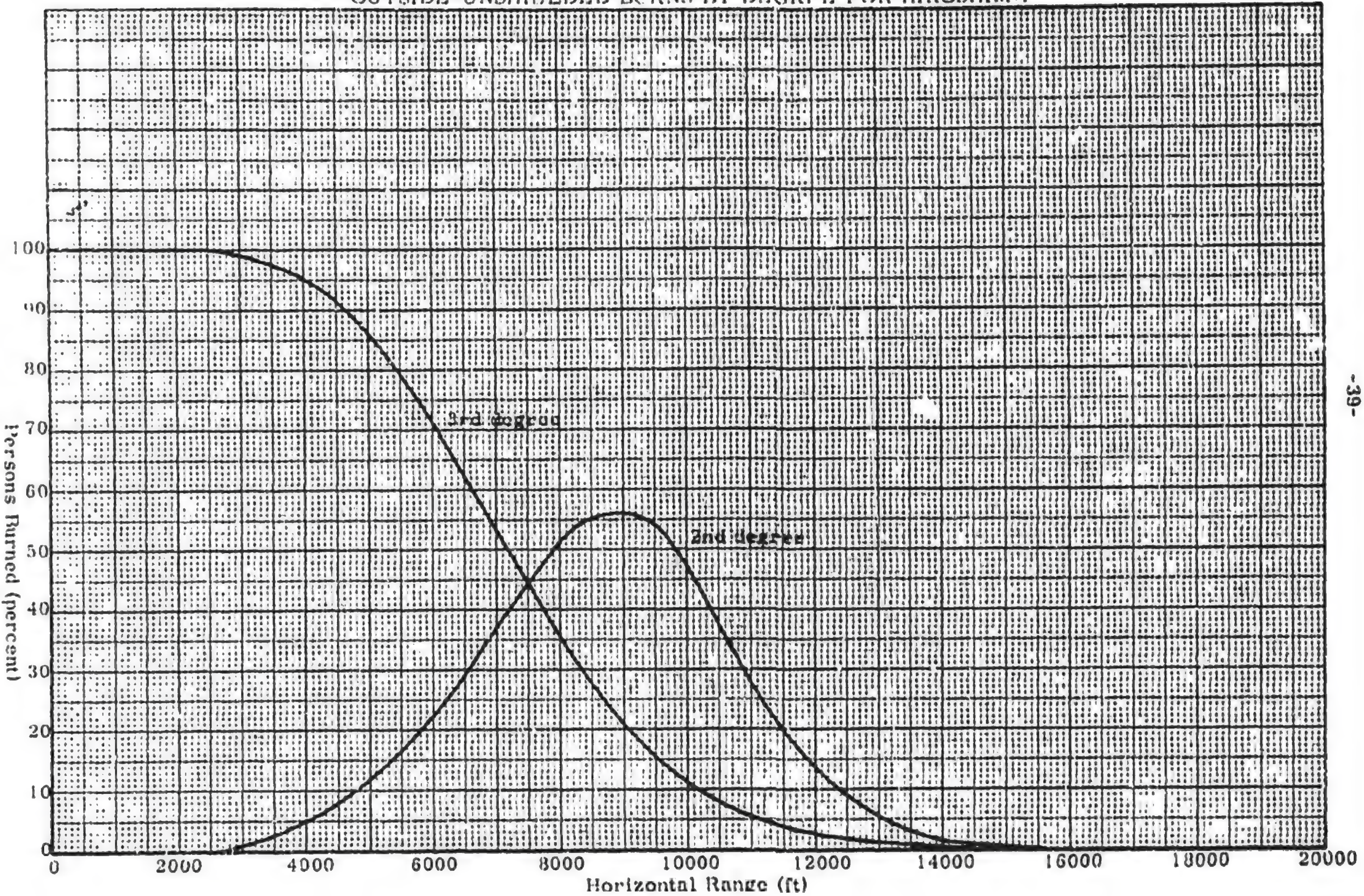


FIG. 28

OUTSIDE-UNSHIELDED BURNS BY DEGREE FOR NAGASAKI

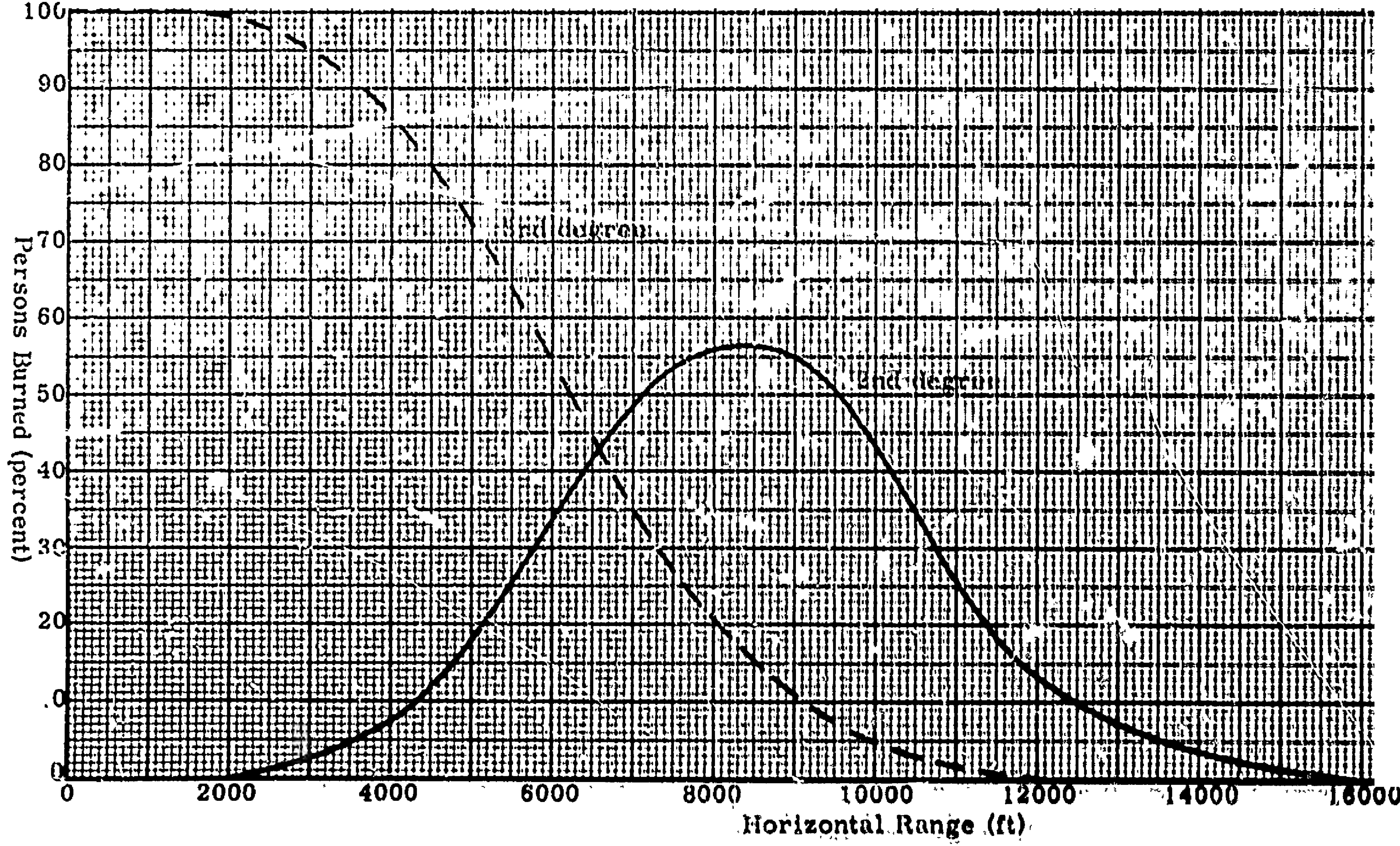


FIG. 29

BURN MORTALITY VERSUS PERCENT AREA BURNED FOR NAGASAKI

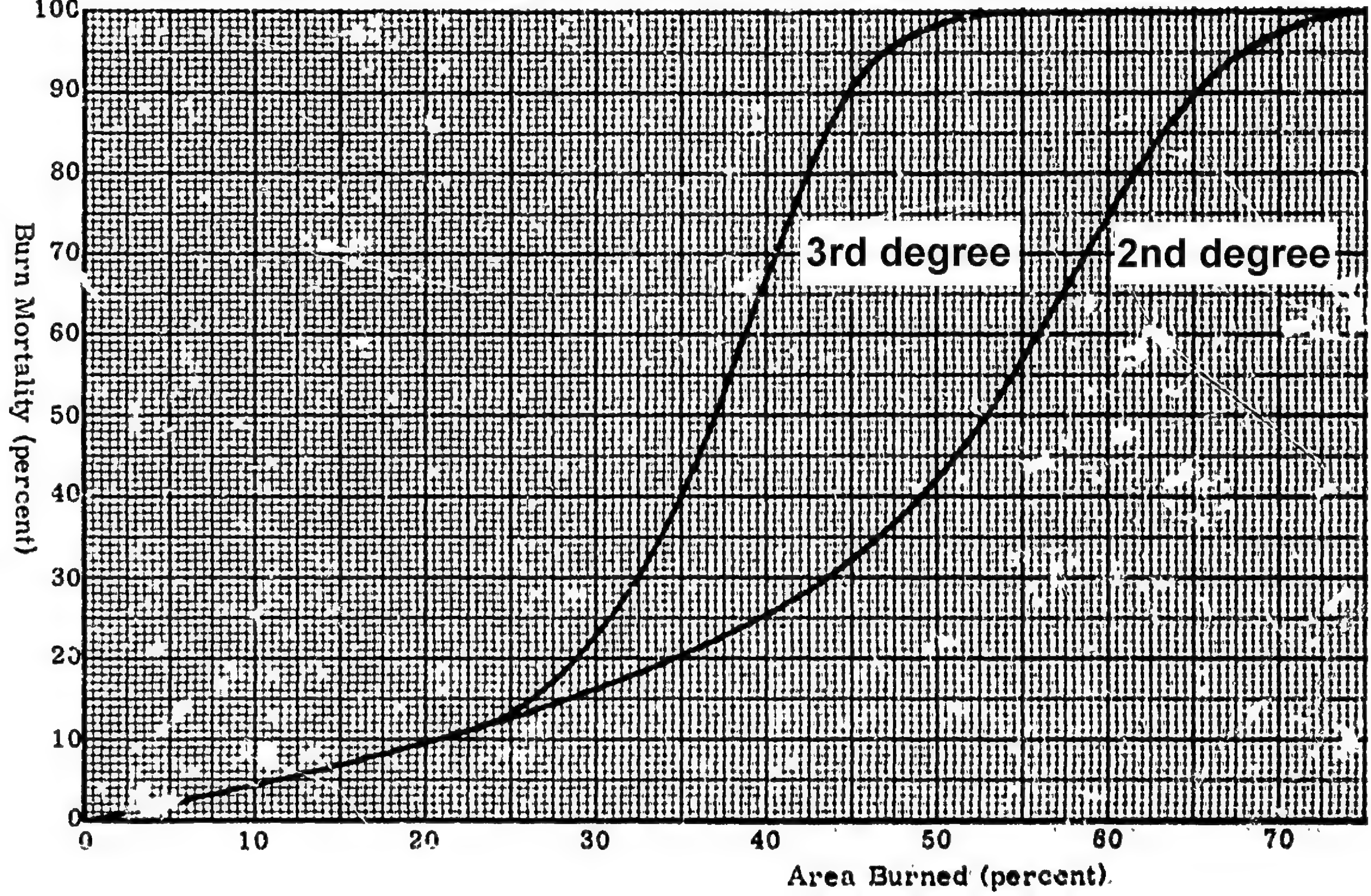


FIG. 43
HIROSHIMA INJURY CURVES FOR VEHICLES

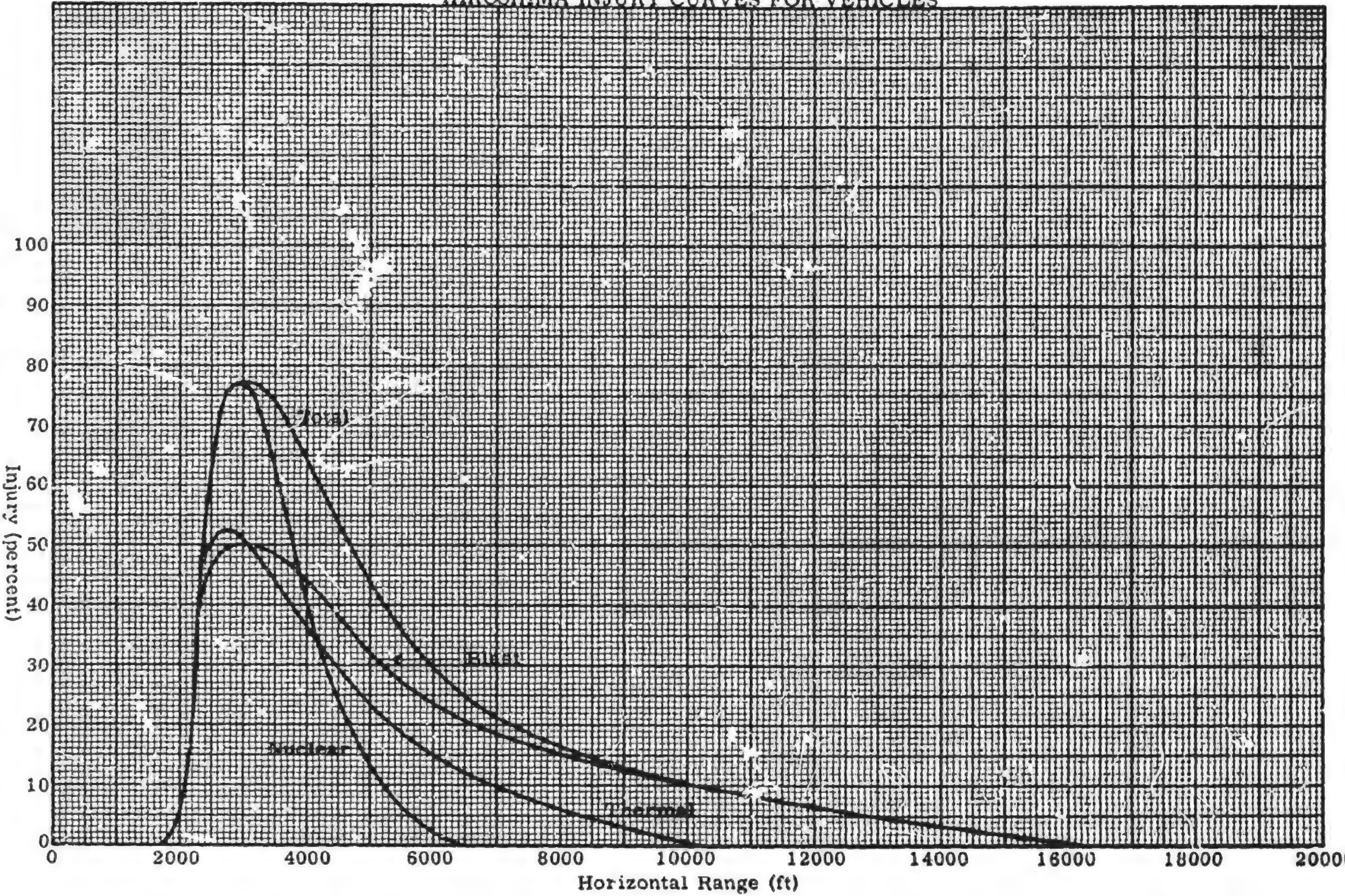


FIG. 47

HIROSHIMA INJURY CURVES FOR OUTSIDE-UNSHIELDED CATEGORY

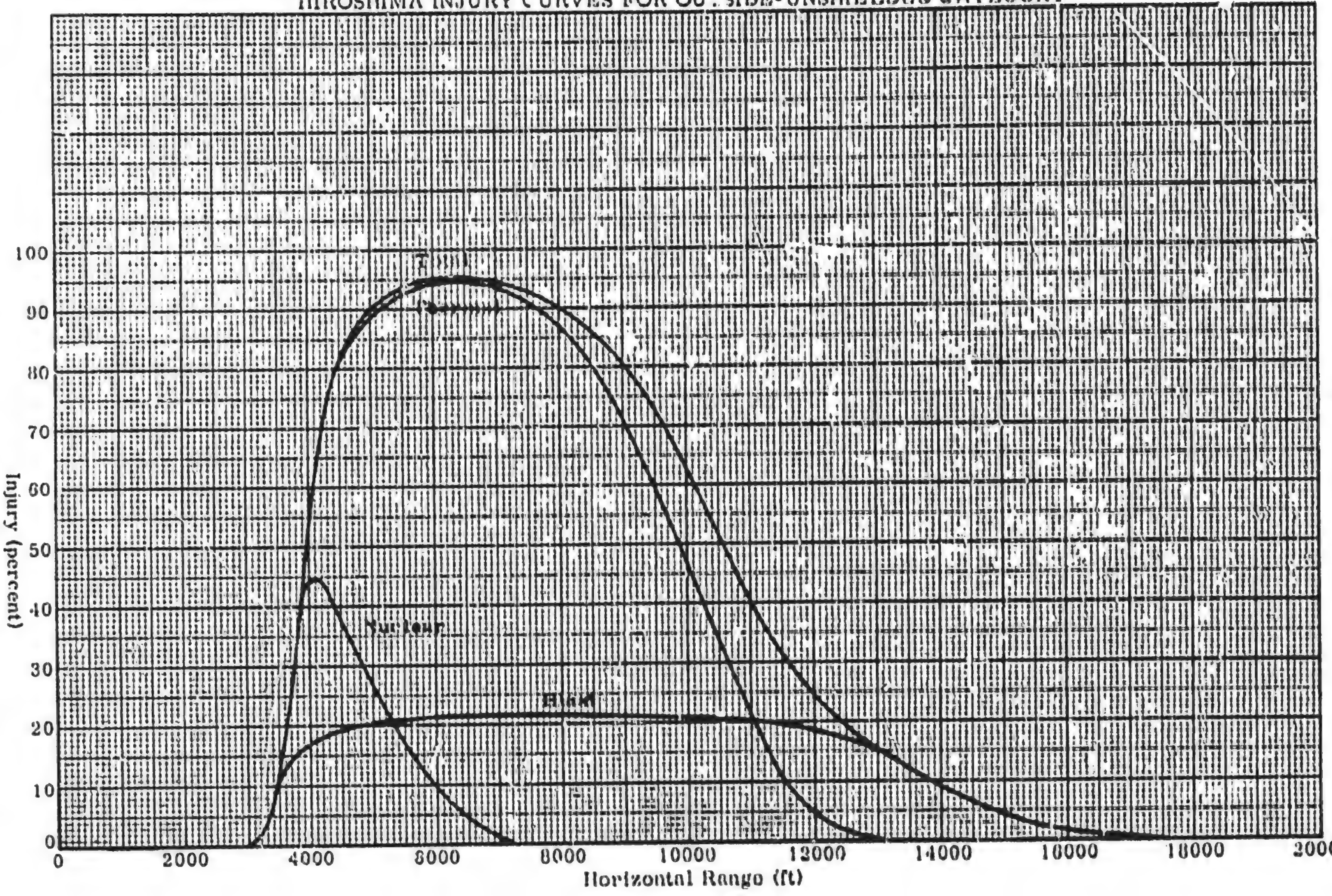


FIG 58

NAGASAKI INJURY CURVES FOR OUTSIDE-UNSHIELDED CATEGORY

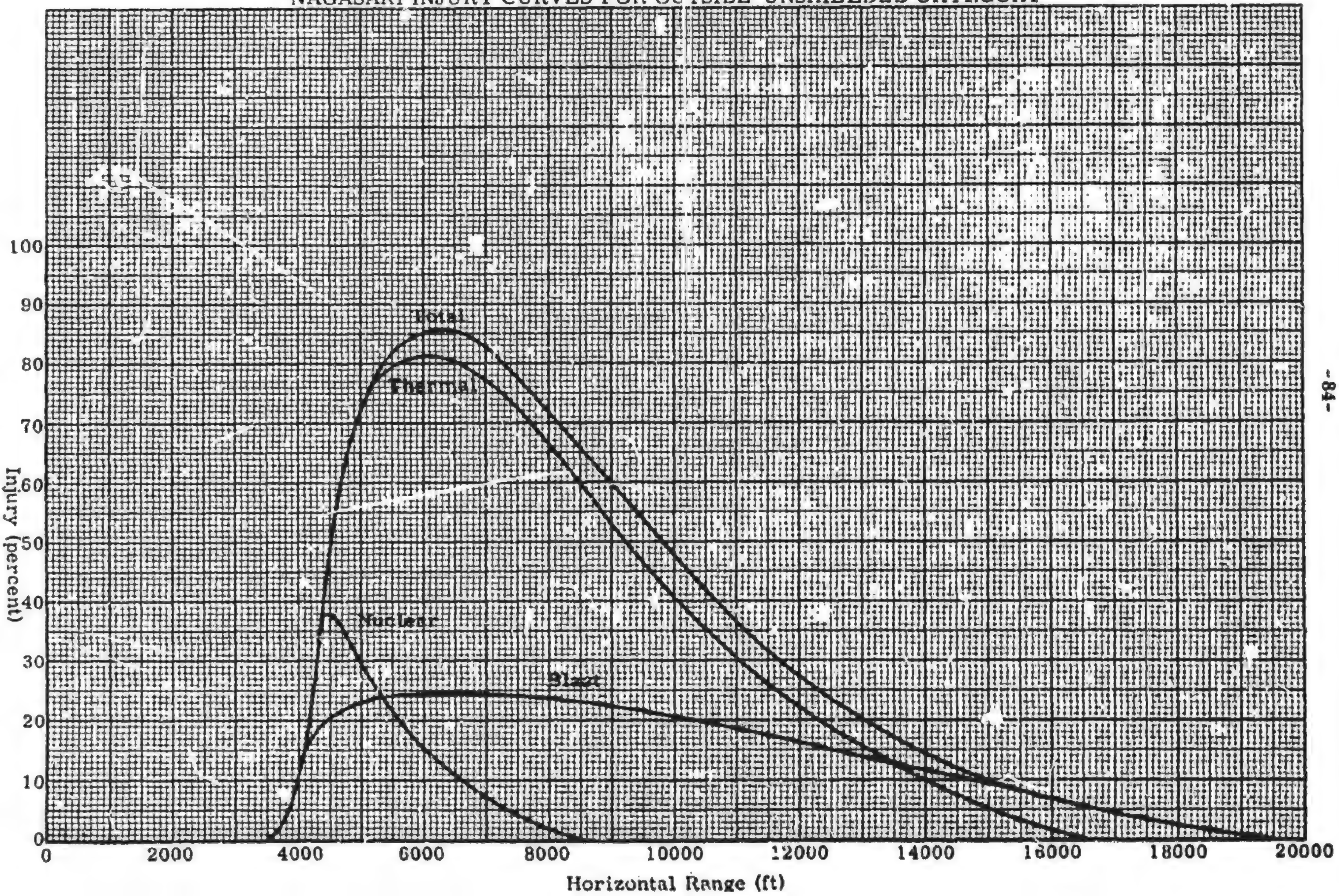
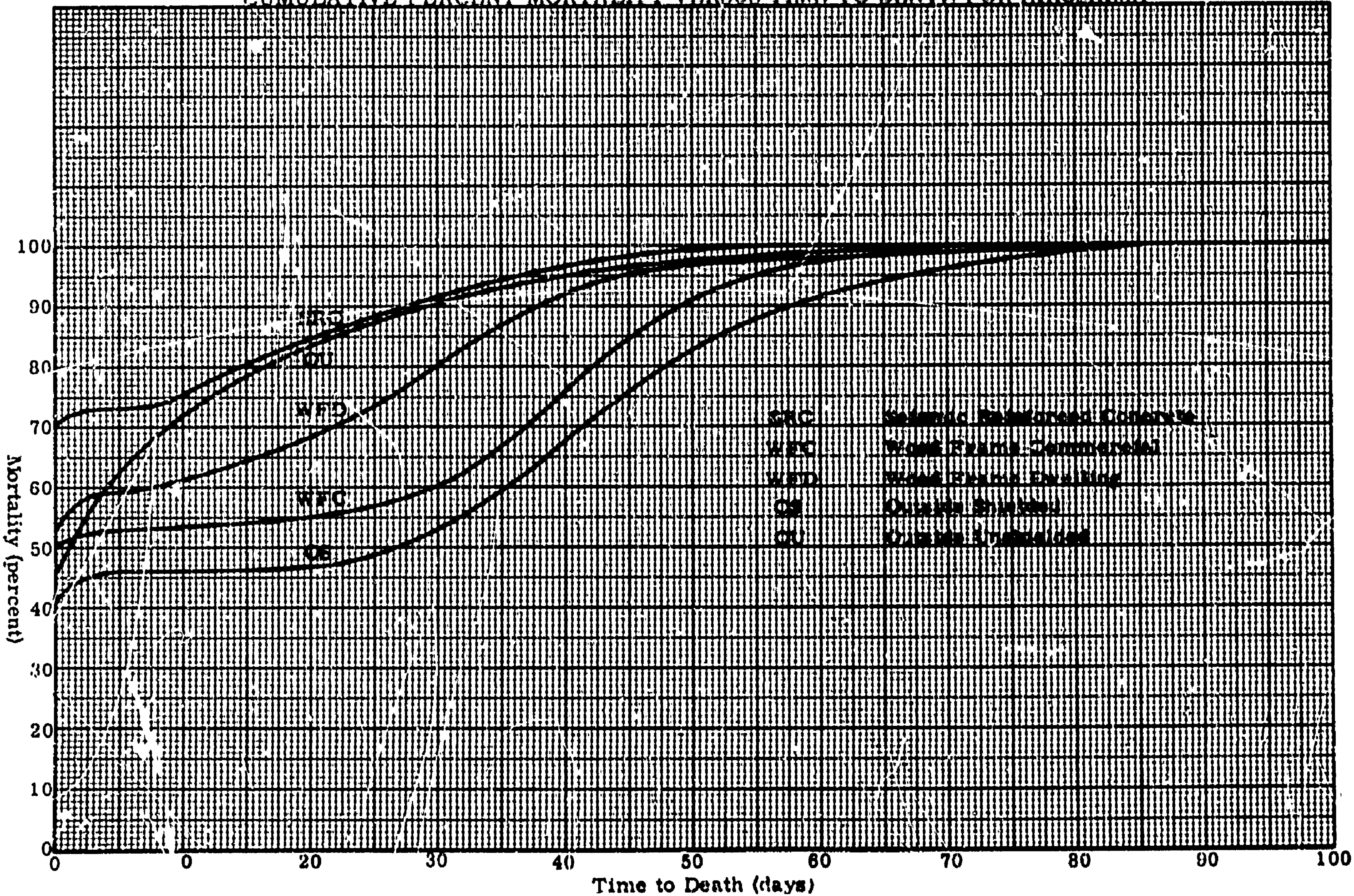


FIG. 61

CUMULATIVE PERCENT MORTALITY VERSUS TIME TO DEATH FOR HIROSHIMA



~~CONFIDENTIAL~~

DEPARTMENT OF THE ARMY TECHNICAL MANUAL
DEPARTMENT OF THE NAVY
DEPARTMENT OF THE AIR FORCE
MARINE CORPS PUBLICATIONS

TM 23-200
OPNAV INSTRUCTION 03400.1B
AFL 136-1
NAVMC 1104 REV

CAPABILITIES OF ATOMIC WEAPONS (U)

Prepared by
Armed Forces Special Weapons Project

DEPARTMENTS OF THE ARMY, THE NAVY AND THE AIR FORCE

REVISED EDITION NOVEMBER 1957

~~CONFIDENTIAL~~

PHENOMENA AT VARIOUS SCALED BURST HEIGHTS

Figures 5–2A, B, and C show the range from ground zero of various physical phenomena when a burst is on the surface, at a scaled height of 250 $W^{1/3}$ feet, and at a scaled height of 650 $W^{1/3}$ feet, respectively. They are presented primarily for rapid visual comparison of the distance to which the various physical phenomena will extend, and secondarily for a rapid determination of the controlling mechanism of damage at any distance for any yield. From data presented in part one, a similar illustration could be prepared for any scaled or actual burst height.

The significance of the various phenomena curves presented varies with the target being considered. The initial and residual radiation curves are the most significant ones for human targets in the open or in shelters. The values chosen for plotting represent the following:

- 5 *r*—No obvious effect on personnel.
- 100 *r*—Non-lethal dose causing sickness in a few personnel, but permitting a unit to remain operationally effective.
- 450 *r*—Dose lethal within 30 days to 50 percent of personnel exposed.
- 10,000 *r*—Free field dose which will produce a dose of 100 *r* for personnel within a shelter having a dose transmission factor of 0.01.

The blast and thermal radiation curves cannot be related directly to damage, because of the increasing duration of blast and thermal phenomena with increasing yield and the dependence of the degree of damage sustained on the duration of the damage-producing effect. To assist in relating the curves presented to expected damage, the following table shows the variation with yield of the magnitude of weapon phenomena required to cause various degrees of damage to certain selected targets. (Refer to secs. VI through XII for a more detailed presentation of damage criteria.)

	1 KT	*100 KT*	*10 MT*
Thermal effects:		*(cal/cm²)*	
Second degree bare skin burn	4	5. 1	9. 1
Newspaper ignition	2. 9	5. 1	9. 1
White pine charring	10	18	32
Army khaki summer uniform destruction	18	31	56
Navy white uniform destruction	34	60	109
Blast effects (in the Mach region):			
Severe damage to overpressure sensitive structures:		*(PSI overpressure)*	
Blast-resistant designed buildings	50	40	35
Reinforced concrete buildings	10. 5	9. 5	9
Monumental wall bearing buildings	20	15	15
Wood frame housing	3	3	3
Window pane breakage	0. 5	0. 5	0. 5
Severe damage to dynamic pressure sensitive structures:		*(PSI dynamic pressure)*	
Light steel frame single story buildings	4. 5	2	0. 9
Heavy steel frame single story buildings	6	3	1. 5
Steel frame multistory buildings	7. 5	2. 5	0. 9
150′–250′ span truss bridges	50	8	5. 5

Some curves are extrapolated beyond data presented in part one, since it is felt that the relationships between phenomena as shown will hold in those regions where there is little supporting knowledge, even though the actual values may be questionable. Since thermal curves are extended beyond one-half the visibility, their interpretation in that region must be approached with caution. In figures B and C, the relative air density would decrease as the actual height of burst is increased in a real case. However, it is held constant for illustrative purposes here. The conversion from slant range to ground range, plus the variation in enhancement of gamma radiation, causes the change in the shape of the radiation curves with change of burst height. Fallout contours are elliptical; only the downwind extent is shown.

Reliability. Varies with the phenomenon of interest. See part one.

Related material.

See paragraph 5.5.

SECTION VI
PERSONNEL CASUALTIES

6.1 Air Blast and Mechanical Injury

a. General. The air blast from a nuclear detonation may cause casualties among human beings in two ways—direct blast injury and indirect blast injury.

b. Direct Blast Injury.

(1) *Crushing forces.* Although the human body is relatively resistant to the crushing forces which result from air blast loading, large pressure differences resulting from blast wave overpressures may cause damage to lungs, abdominal organs and other gas-filled body organs. Based on data obtained from high explosive detonations, it is estimated that on the order of 200 to 300 psi peak overpressure is required to cause death in humans, provided no translational motion occurs. However, the long duration of the overpressure from a nuclear explosion may appreciably lower this peak overpressure criterion. In any event, no crushing injury other than ear drum rupture occurs for a peak overpressure of less than 35 psi. Although ear drum rupture may result from peak overpressures of 7 to 15 psi, this is not considered a disabling injury, and the overall effectiveness of a unit will not be hampered by the occurrence of these injuries. Therefore, since other damage producing effects are overriding at pressures above 35 psi, crushing forces as such need not be considered as a primary mechanism of producing casualties to personnel in the field.

In structures of certain types, such as bomb shelters or permanent type gun emplacements, where adequate shielding exists against thermal and nuclear radiation, the design of the structure may permit the build-up of blast pressure due to multiple reflections. Blast injuries may therefore occur inside even though the free air overpressure outside the structure would not be sufficient to cause injury.

Both ear drum rupture and other bodily damage which may result from overpressure are largely dependent upon the characteristics of the shock front. If the rise time is long, the body organs are subjected to less severe pressure differences and also are able to better adapt themselves to high overpressure. Consequently, the probability of injury is reduced.

(2) *Translational Forces.*

(*a*) *Mechanisms.* The translational force to which an individual exposed to a blast wave is subjected depends primarily on drag forces. Since the human body is relatively small and the blast wave almost immediately envelops it, the diffraction process is short. The translational force may be predicted with reasonable accuracy if the burst position, yield, terrain, and the orientation of the human body are known. Since the translational force applied depends on the exposed frontal surface area of the human body, an individual standing in the open is subjected to much larger translational forces than an individual lying on the ground surface. Thus, assuming a prone position at the instant a nuclear bomb flash is detected is quite effective in reducing the likelihood of injuries resulting from bodily translation. In addition, the translational forces are appreciably reduced for an individual

who is behind a building or in a shelter which is sufficiently blast resistant. The degree of protection afforded by a foxhole against injury resulting from translation is not too well known at present. However, appreciable protection should be provided if the foxhole is deep enough to prevent lifting therefrom.

(*b*) *Criteria for injury.* Although no direct correlation is known between translational motion parameters and injury, it is reasonable to assume that some relationship exists. The initial rate of acceleration, the motions of various parts of the body while being translated, and the nature of the impact, all certainly contribute to injury. Probably most injuries will result from impact. The severity of injury will depend on the nature of the object or objects with which the translated body collides, the nature of the impact, whether glancing or solid, and the velocity at impact. Some individuals may survive a large translation, whereas others may be severely injured or killed by a relatively small translation. Because increased yield results in increased positive phase duration, attainment of velocities sufficient to cause injury on impact will occur for lower peak pressures. The manner of impact likewise depends on the nature of the terrain and surface configuration. If solid impact occurs, it is estimated that body velocities of about 12 feet per second will produce serious injury approximately 50 percent of the time, while collision at about 17 feet per second will result in approximately 50 percent mortality. Figure 6–1 is a plot of burst height vs. ground range at which 50 percent of standing and prone personnel in the open are expected to become direct blast casualties. The curves are drawn for 1 KT and may be scaled to other yields by multiplying the burst heights by the cube root of the yield and the ground distance by the four-tenths power of the yield.

c. *Indirect Blast Injury.*

(1) *General.* Indirect blast casualties result from burial by debris from collapsed structures with attendant production of fractures and crushing injuries, from missiles placed in motion by the blast wave, or from fire or asphyxiation where individuals are prevented from escaping the wreckage.

(2) *Personnel in structures.* A major cause of personnel casualties in cities is structural collapse and damage. The number of casualties in a given situation may be reasonably estimated if the structural damage is known. Table 6–1 shows estimates of casualty production in two types of buildings for several damage levels. Data from Section VII may be used to predict the ranges at which specified structural damage occurs. Demolition of a brick house is expected to result in approximately 25 percent mortality, with 20 percent serious injury and 10 percent light injury. On the order of 60 percent of the survivors must be extricated by rescue squads. Without rescue they may become fire or asphyxiation casualties, or in some cases be subjected to lethal doses of residual radiation. Reinforced concrete structures, though much more resistant to blast forces, produce almost 100 percent mortality on collapse. The figures of table 6–1 for brick homes are based on data from British World War II experience. It may be assumed that these predictions are reasonably reliable for those cases where the population is in a general state of expectancy of being subjected to bombing and that most personnel have selected the safest places in the buildings as a result of specific air raid warnings. For cases of no prewarning or preparation, the number of casualties is expected to be considerably higher. To make a good estimate of casualty production in structures other

than those listed in table 6–1, it is necessary to consider the type of structural damage that occurs and the characteristics of the resultant missiles. Glass breakage extends to considerably greater ranges than almost any other structural damage, and may be expected to produce large numbers of casualties at ranges where personnel are relatively safe from other effects, particularly for an unwarned population.

Table 6–1. Estimated Casualty Production in Structures for Various Degrees of Structural Damage

	Killed outright	Serious injury (hospitalization)	Light injury (No hospitalization)
1–2 story brick homes (high explosive data):	*Percent*	*Percent*	*Percent*
Severe damage	25	20	10
Moderate damage	<5	10	5
Light damage	------	<5	<5
Reinforced-concrete buildings (Japanese data, nuclear):			
Severe damage	100	------	------
Moderate damage	10	15	20
Light damage	<5	<5	15

Note. These percentages do not include the casualties which may result from fires, asphyxiation, and other causes from failure to extricate trapped personnel. The numbers represent the estimated percentage of casualties expected at the maximum range where the specified structural damage occurs. For the distances at which these degrees of damage occur for various yields, see section VII.

(3) *Personnel in vehicles.* Personnel in vehicles may be injured as a result of the response of the vehicle to blast forces. Padding where applicable and the use of safety belts, helmets, and harnesses virtually eliminates this source of casualties, at least within armored vehicles. In the absence of these protective devices, serious lacerations may result from impact with sharp projections within the vehicle interiors. Comparative numbers of casualties are almost impossible to assess in this respect due to the many variables which are involved.

(4) *Personnel in the open.* Missiles translated by the blast wave may be a significant source of injury to exposed personnel. Missiles having low velocities, if of sufficient size, may cause crushing injuries. In contrast, penetrating wounds may be caused by high velocity missiles. The missile density and characteristics are largely a function of the target. Where the target area is relatively clean and there is little material present subject to fragmentation and displacement, fewer injuries from missiles are expected in the open than from debris within structures at comparable distances. When the target complex presents many possible sources of missiles this may not be the case. Personnel in a prone position are less likely to be struck by flying missiles than those who remain standing. Those who succeed in getting into bunkers, foxholes, or in defilade probably will achieve almost complete protection from the flying missile hazard.

6.2 Thermal Injury

a. Introduction. Before attempting to predict the number of thermal casualties which occur in a given situation, it is necessary to recognize the factors which influence the number and distribution of casualties to be expected. These factors include—the distribution or deployment of personnel within the target area, whether proceeding along a road, in foxholes, standing or prone, in the open or under natural cover; orientation with respect to the bomb; clothing, including number of layers, color, weight, and whether the uniform includes helmets, gloves, or other devices which might protect the bare skin, such as flash creams; and natural shielding. These parameters which define the target must be considered along with the factors which define the source of radiation such as yield of the weapon, height of burst, and visibility, as discussed in section III. In many target complexes, a large percentage of thermal casualties may be due to secondary burns. This is particularly true in cities and industrial areas where a major part of the direct radiation may be shielded by intervening structures. Because of the number of factors involved, it is necessary to analyze each particular target situation in order to make realistic predictions of the thermal casualties to be expected.

b. Primary Radiant Energy Burns. Damage to bare skin through the production of burns may be directly related to the radiant exposure and the rate of delivery of the thermal radiation, both of which are yield dependent. For a given total exposure, as the weapon yield increases, the thermal radiation is delivered over a longer period of time and thus at a lower rate. This allows energy loss from the skin surface by conduction to the deeper layers of the skin and by convection to the air. Thus, a given level of damage also is yield dependent. Critical radiant exposures for the production of two degrees of burn on bare skin as a function of yield are presented in figure 6–2 for normal incidence of radiation. Although the data are presented as a single curve, it must be recognized that there will be variations due to factors such as skin color (i. e., darker skin requires a lesser exposure to produce a given severity of burn) and skin temperature (i. e., colder skin as is found in winter or in arctic climates requires a greater exposure to produce the given burn). The curves represent those radiant exposures which will burn 50 percent of any group, including these variants. A first degree burn is defined as one which shows redness; a second degree burn exhibits partial skin destruction or blistering.

c. Burns Under Clothing. Clothing reflects and absorbs much of the thermal radiation incident upon it and thereby protects the wearer against flashburn. In some cases, the protection is complete, but in many cases it is partial in that clothing merely reduces the severity of injury rather than preventing it. At large radiant exposures, there is the additional possibility that the glowing or ignition of the clothing could deliver additional energy to the skin, thereby causing a more severe injury than bare skin would have suffered. There are many factors which contribute to the degree of protection which clothing affords the underlying skin. The thermal resistance of the clothing material itself is probably the most important, as skin burns under undamaged cloth are rarely seen unless the cloth is in close contact with the skin. Other factors are the weight and weave of the fabric; the number of clothing layers worn; the spacing between layers and between the inner layer and the skin; the moisture content, initial temperature, and color of the cloth; the amount and kind of dirt in the cloth; the wind velocity and direction across the surface of the cloth; etc.

The complexity of the interrelations among the above factors makes an accurate prediction extremely difficult. Table 6–2 lists various estimates of radiant exposures required to effect burns under clothing. These values are considered representative of some field conditions, within the limitations due to the varying factors described above.

Table 6–2. Critical Radiant Exposures for Burns Under Clothing

(Expressed in cal/cm² incident on outer surface of cloth)

Clothing	Burn	1 KT	100 KT	10 MT
Summer Uniform	1°	8	11	14
(2 layers)	2°	20	25	35
Winter Uniform	1°	60	80	100
(4 layers)	2°	70	90	120

Note. These values are sensitively dependent upon many variables which are not easily defined (see text), and are probably correct within a factor of two.

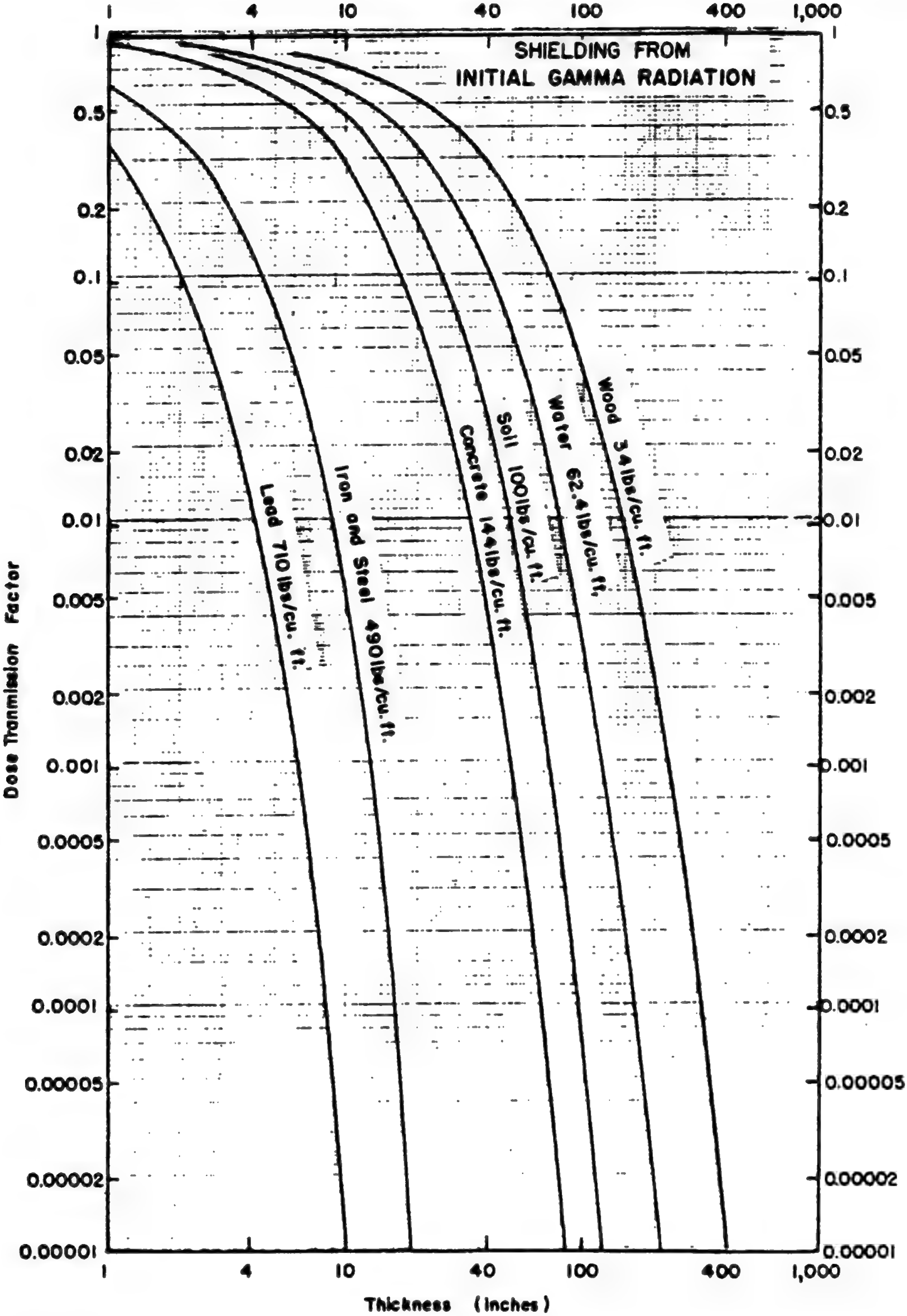
d. The Combat Ineffective. A useful term in the discussion of effects of thermal radiation on personnel is "the combat ineffective." A combat ineffective is defined as a person who, because of his injuries, is no longer capable of carrying out his assigned tasks. This is differentiated from the more common term "casualty," which is defined as an individual whose injuries require medical attention. Damage to certain areas of the body produces a greater number of combat ineffectives than damage to other areas. Burns in the area surrounding the eyes which eventually cause the eyes to swell shut, and burns to the hands which lead to loss of mobility are particularly apt to cause ineffectiveness.

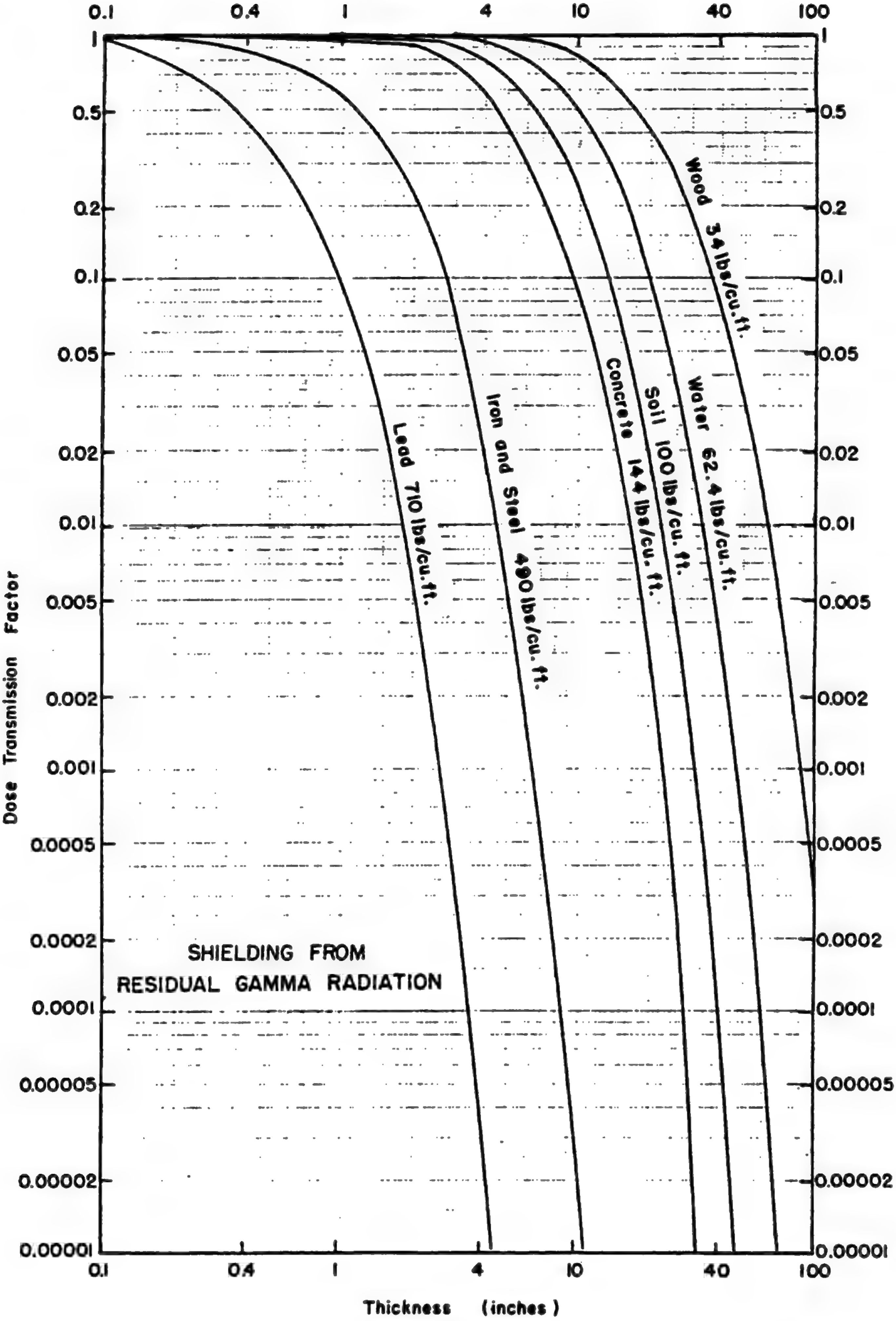
If a sufficient portion of the total body area is burned, physiological shock follows and the individual becomes a casualty. When more than 10 to 15 percent of the total body area receives second degree burns or worse, shock may be expected. The efficacy of injuries to the hands and eyes in producing combat ineffectives, coupled with the vulnerability of these parts due to lack of protection under ordinary circumstances, indicates the importance of providing protection for these areas when nuclear attack is likely. Table 6–3 presents estimates of the production of combat ineffectives by various degrees of thermal injury.

Table 6–5. Dose Transmission Factors (Interior Dose/Exterior Dose)

Geometry	Gamma rays		Neutrons [a]
	Initial	Residual	
Foxholes [b]	0.05–0.10	0.02–0.10	0.3
Underground—3 feet	0.04–0.05	0.0002	0.002–0.01
Built-up city area (in open)	....	0.7	....
Frame house	0.9	0.3–0.6	0.9–1.0
Basement	0.05–0.5	0.05–0.10	0.1–0.8
Multistory building:			
Upper	0.9	0.01	0.9–1.0
Lower	0.3–0.6	0.1	0.9–1.0
Blockhouse walls:			
9 inches	0.1	0.05	0.3–0.5
12 inches	0.05–0.09	0.01–0.02	0.2–0.4
24 inches	0.01–0.03	0.001–0.002	0.1–0.2
Factory, 200 x 200 feet	....	0.10–0.20	....
Shelter, partly above grade:			
With earth cover—2 feet	0.02–0.04	0.005–0.02	0.02–0.08
With earth cover—3 feet	0.01–0.02	0.001–0.005	0.01–0.05
[redacted] ARMY (b)(1)			
LVT (Landing Vehicle Tracked)	0.5–0.9	....	1.0
Battleships and large carriers [c]:			
15% of crew	1.0	1.0	0.8–1.0
25% of crew	0.2	0.1	0.2–0.8
10% of crew	0.05	0.03	0.05–0.2
50% of crew	0.0005–0.005	0.0003–0.003	0.001–0.05
Cruisers and carriers [c]:			
10% of crew	1.0	1.0	0.8–1.0
20% of crew	0.5	0.3	0.4–0.8
30% of crew	0.1–0.3	0.1	0.1–0.4
40% of crew	0.005–0.1	0.003–0.05	0.01–0.1
Aircraft	1.0	....	1.0
Destroyers, transports, and escort carriers [c]:			
10% of crew	1.0	1.0	0.8–1.0
20% of crew	0.7	0.5	0.6–0.8
30% of crew	0.4	0.2	0.3–0.6
40% of crew	0.1–0.4	0.1	0.1–0.3

[a] Estimated values.
[b] No line-of-sight radiation received.
[c] Crew at General Quarters.


SHIELDING FROM
INITIAL GAMMA RADIATION
Dose Transmission Factor
Thickness (inches)
Lead 710 lbs/cu. ft.
Iron and Steel 490 lbs/cu. ft.
Concrete 144 lbs/cu. ft.
Soil 100 lbs/cu. ft.
Water 62.4 lbs/cu. ft.
Wood 34 lbs/cu. ft.
1
4
10
40
100
400
1,000
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
0.0005
0.0002
0.0001
0.00005
0.00002
0.00001


SHIELDING FROM
RESIDUAL GAMMA RADIATION
Dose Transmission Factor
Thickness (inches)
0.1
0.4
1
4
10
40
100
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
0.0005
0.0002
0.0001
0.00005
0.00002
0.00001
Lead 710 lbs/cu. ft.
Iron and Steel 490 lbs/cu. ft.
Concrete 144 lbs/cu. ft.
Soil 100 lbs/cu. ft.
Water 62.4 lbs/cu. ft.
Wood 34 lbs/cu. ft.

DNA EM-1
PART I
1 JULY 1972

DEFENSE NUCLEAR AGENCY EFFECTS MANUAL NUMBER 1

CAPABILITIES OF NUCLEAR WEAPONS

PART I
PHENOMENOLOGY

HEADQUARTERS
Defense Nuclear Agency
Washington, D.C. 20305

EDITOR
PHILIP J. DOLAN
STANFORD RESEARCH INSTITUTE

[redacted]

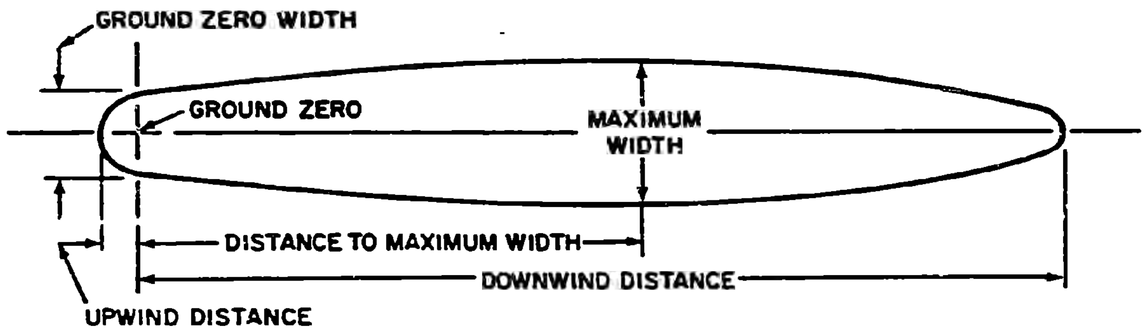


Figure 5-24. (U) Idealized Early Fallout Dose Rate Contour (U)

[redacted] called effective wind, as described in paragraph 5-20. Usually wide discrepancy from the idealized pattern will result if there are large directional shears in the winds from the surface up to the altitudes of the stabilized cloud. Such shears can distort the idealized pattern seriously, so that, in practice, radical departures from the idealized patterns can be expected. Figure 5-25 compares the idealized dose rate contour pattern to the observed pattern normalized to 1 hour after shot SMALL BOY, a low yield shot in Nevada during which the wind shear was not [illegible] winds had an effective velocity of about 8 knots and an effective shear of about 30 degrees (effective velocity and effective shear are defined in paragraph 5-20). The idealized pattern is shown for an effective velocity of 10 knots and an effective shear of 15 degrees, for the reasons explained in paragraph 5-20. The downwind distance is expected to increase and the crosswind distance to decrease both with an increase in velocity and with a decrease in shear. These tendencies are noticeable in Figure 5-25; however, for this case of low yield and minimal shear, the idealized contours represent a reasonable approximation of the observed contours.

[redacted] Figure 5-26 shows a hodograph of a typical summer wind structure over Fort Worth, Texas. This is an example of a severely sheared wind structure. The average wind speed to altitudes of the stabilized cloud from a 2 Mt burst is about 10 knots, but, as a result of directional changes, the effective velocity is only 2.5 knots. The direction of this effective wind is 43.5 degrees east of north.

[redacted] Figure 5-27 shows a comparison of the idealized dose rate contours for a 2 Mt explosion on the surface and the contours computed by the "Defense Land Fallout Interpretive Code (DELFIC)" (see bibliography) for the wind hodograph shown in Figure 5-26 assuming that the winds stayed constant in time and distance. While this comparison is not a comparison with actual data, it is a comparison with the results of a complex computer code that was developed independent of empirical data and which has demonstrated a very good agreement with available data. The general direction as well as the areas of the two patterns are quite divergent. This comparison is intended to illustrate the lack of confidence that can be placed in the idealized contours for prediction of a fallout pattern for a particular explosion, even if meteorological data

[redacted]

[redacted]

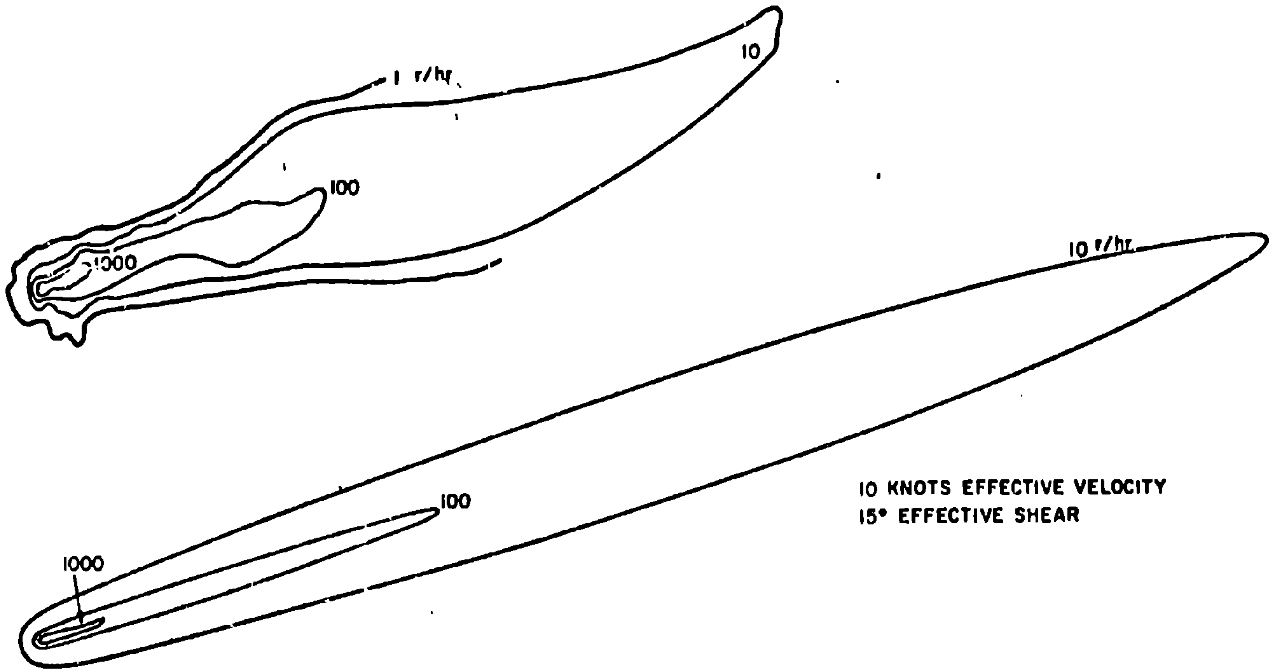
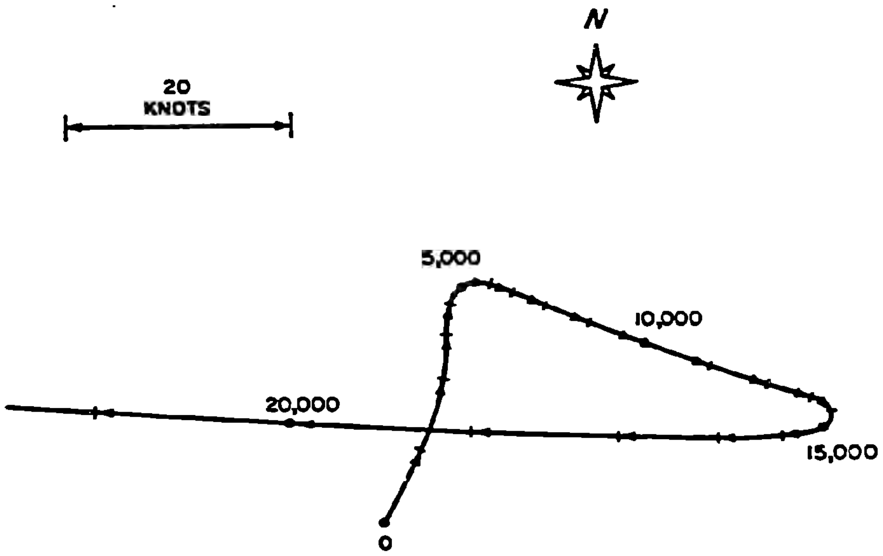


Figure 5-25. [redacted] Comparison of Idealized Dose Rate Contours with Observed Contours from a Low Yield Explosion [redacted]

[redacted]



NOTE: NUMBERS ARE METERS OF ALTITUDE.

Figure 5-26. [redacted] Hodograph of a Typical Summer Wind Structure Over Fort Worth, Texas [redacted]

[redacted]

at the burst point are known. The contours for the idealized curves were extrapolated to a speed of 2.5 knots even though extrapolation below 10 knots is not recommended. On the other hand, for small yields, or for the case of many weapons, the total dose predicted by the idealized contours over large areas probably would provide a reasonable basis upon which to base casualty predictions.

5-20 Dose Rate Contour Dimensions [redacted]

[redacted] Figures 5-28 through 5-37 may be used to draw idealized dose rate contours for land surface explosions with yields between 0.01 kt and 30 Mt. Separate sets of curves are provided for downwind distance, maximum width, and downwind distance to maximum width for effective wind speeds of 10, 20, and 40 knots. Since actual winds are seldom unidirectional and since the radioactive particles that cover the area around ground zero include many that were not carried to high altitudes, the ground zero width is presented independent of wind velocity in Figure 5-37. The upwind distance is estimated to be one-half the ground zero contour widths, i.e., they may be represented by a semi-circle, centered at ground zero, with a radius equal to one-half the ground zero width. The dose rate values obtained from the curves correspond to the values existing at a reference time of 1 hour after burst, 3 feet above a hypothetical smooth, infinite plane; therefore, they must be reduced to account for ground roughness. A reduction

[redacted]

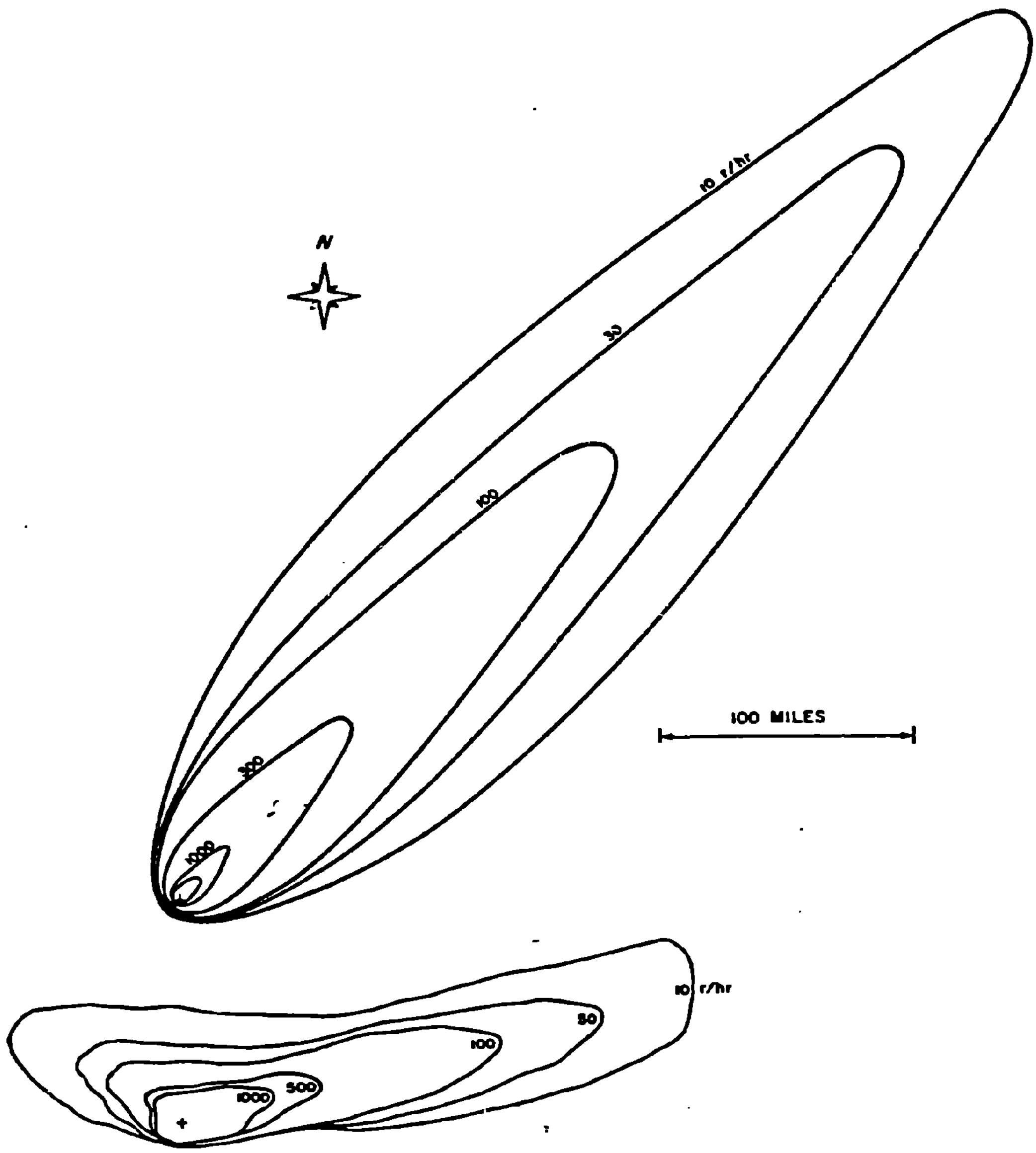


Figure 5-27. [redacted] Comparison of Idealized Dose Rate Contours with Those Calculated by a Complex Computer Code for a 2 Mt Explosion and the Winds of Figure 5-25 [redacted]

[redacted]

[redacted]

factor of 0.7 is appropriate for reasonably level terrain. A factor of 0.5 to 0.6 would be more appropriate for rough and hilly terrain. If additional shielding exists (e.g., foxholes, buildings, tanks), additional shielding factors should be obtained from Section VI, Chapter 9.

[redacted] To obtain the effective wind for use with Figures 5-28 through 5-36, a wind hodograph similar to that shown in Figure 5-26 should be prepared. The vector averages of the winds from ground zero to the base of the stabilized cloud and to the top of the stabilized cloud should then be obtained. The average of these two average vectors is the effective wind for use with Figures 5-28 through 5-36. The heights of the bottom and top of the stabilized cloud are shown as a function of yield in Figures 5-38 and 5-39, respectively. For wind speeds between the values of 10, 20, and 40 knots that are shown in Figures 5-28 through 5-36, contour values may be obtained by linear interpolation. Extrapolation to values below 10 knots or above 40 knots is not recommended.

[redacted] As used herein the term "effective shear" refers to the angle between the average vectors to the bottom and top of the stabilized cloud. In the absence of a sufficient quantity of test data with which empirical curves for determining the idealized contours could be con- [illegible] were generated by use of the Defense Land Fallout Interpretive Code (DELFIC) (see bibliography). An effective shear of 15 degrees was used in the computer calculations from which the curves of Figures 5-28 through 5-36 were derived. In general, increased wind velocity tends to lengthen and narrow the pattern, while increased directional shear tends to shorten and widen the pattern. An effective velocity and an effective directional shear do not define a unique wind structure, i.e., different wind structures could have the same effective velocity and directional shear. It is not recommended that any attempt be made to change the contour values for effective directional shears different from 15 degrees; however, the user should be aware that differences from this value are more likely to result in idealized contours that are farther from reality than if the shear is nearly equal to 15 degrees.

5-21 Decay of Early Fallout [redacted]

[redacted] Fission products are composed of a complex mixture of over 200 different forms (isotopes) of 36 elements. Most of these isotopes are radioactive, decaying by the emission of beta particles, frequently accompanied by gamma radiation. About 2 ounces of fission products are formed for each kiloton (or 125 lb/Mt) of fission energy yield. The total radioactivity of the fission products initially is extremely large but it falls off rapidly as the result of radioactive decay.

[redacted] At 1 minute after a nuclear explosion, when the residual nuclear radiation is postulated to begin, the gamma ray activity of the 2 ounces of fission products from a 1 kt fission yield explosion is comparable with that of about 30,000 tons of radium. For explosions in the megaton-energy range the amount of radioactivity produced is enormous. Although there is a decrease from the 1 minute value by a factor of over 6,000 by the end of a day, the radiation intensity still will be large.

[redacted] Early fallout consists mainly, but not entirely, of fission products. The following rule indicates how the dose rate of the actual mixture decreases with time: for every seven-fold increase in time after the explosion, the dose rate decreases by a factor of 10. For example, if the radiation dose rate at 1 hour after the explosion is taken as a reference point, then at 7 hours after the explosion the dose rate will have decreased to 1/10; at 7 x 7 = 49 hours (or roughly 2 days) it will be 1/100; and at 7 x 49 = 343 hr (or roughly 2 weeks) the dose rate will be 1/1,000 of that at 1 hour after the burst.

[redacted]

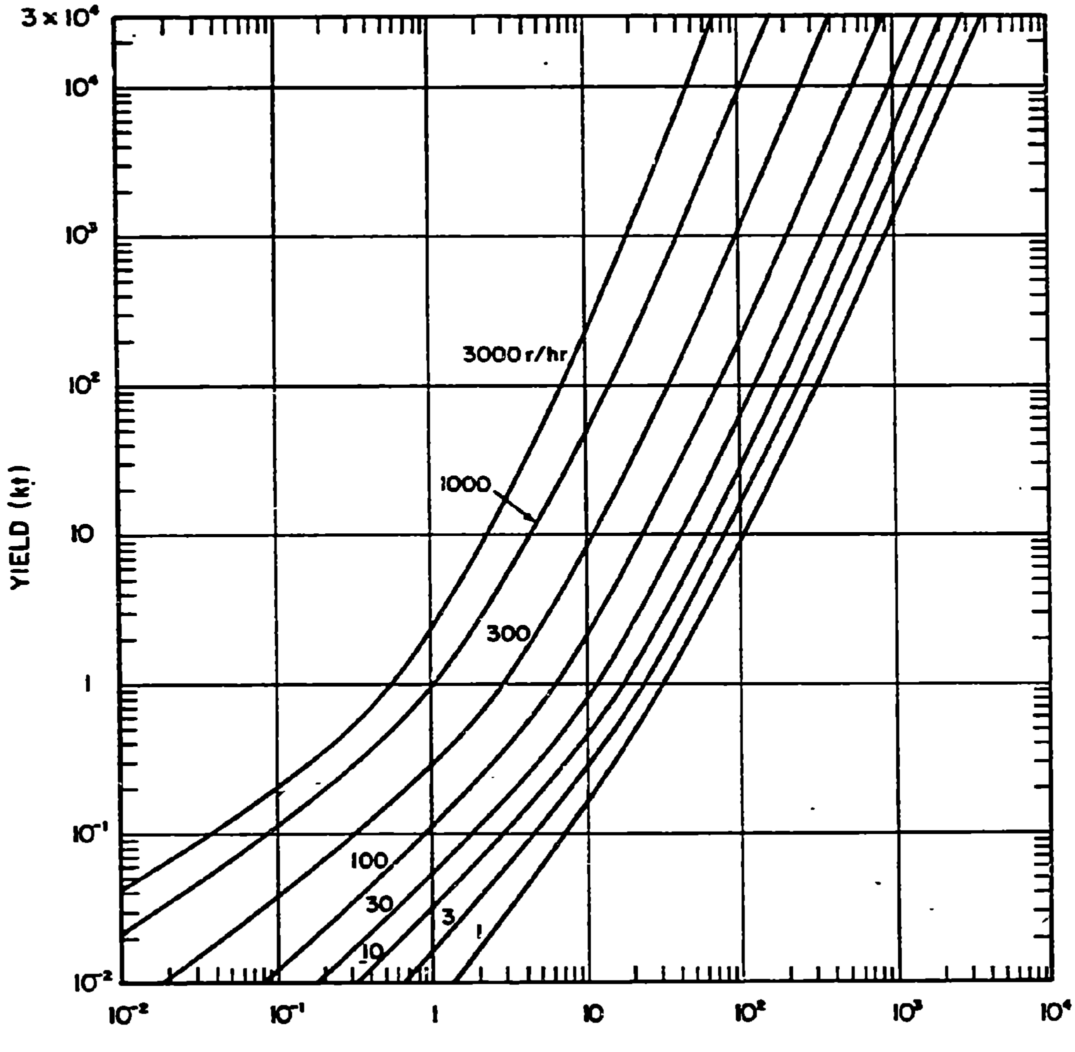


Figure 5-28. [redacted] Downwind Distance as a Function of Yield, 10 Knot Effective Wind [redacted]

[redacted]

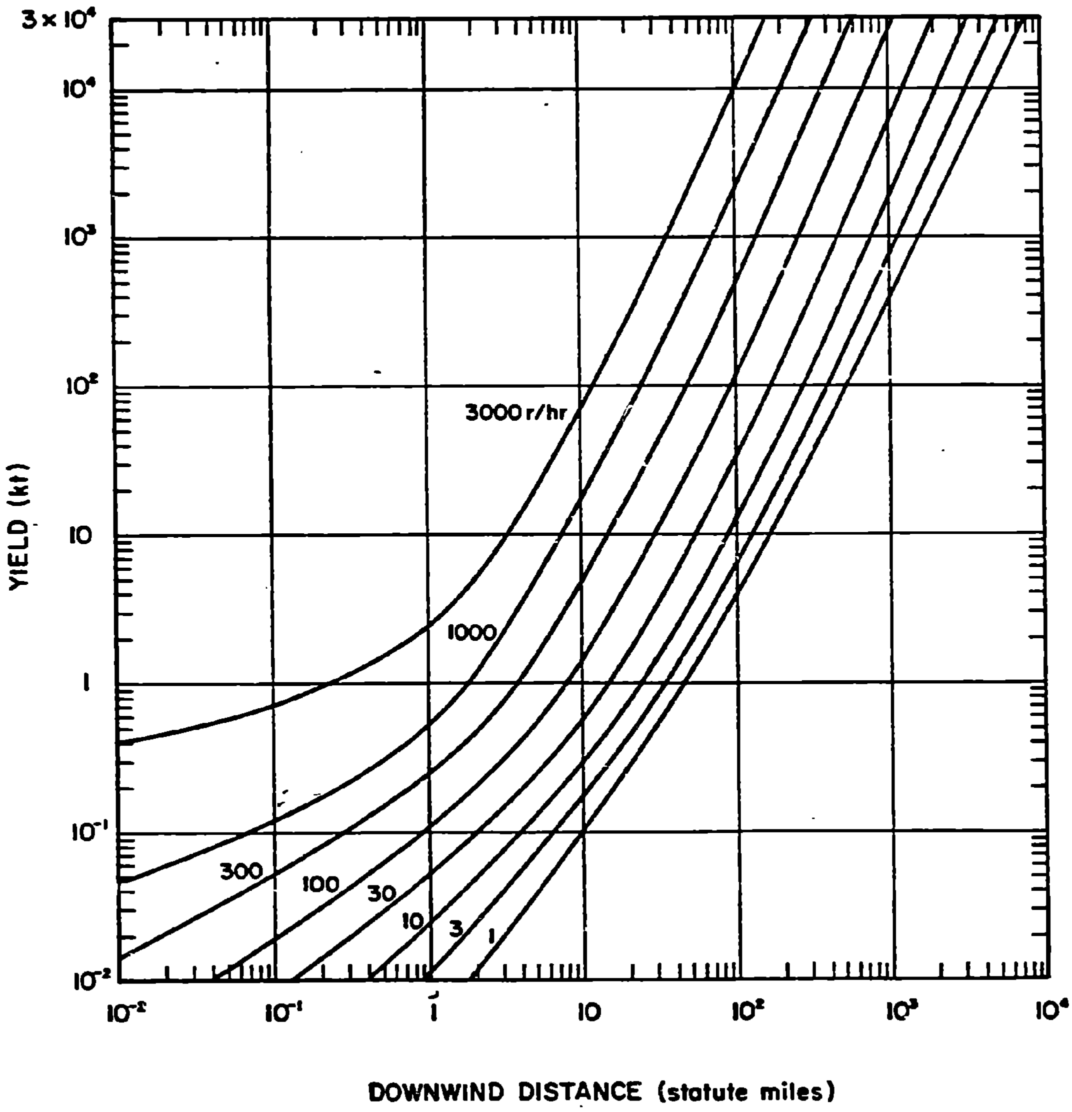


Figure 5-30. [redacted] Downwind Distance as a Function of Yield, 40 Knot Effective Wind [redacted]

[redacted]

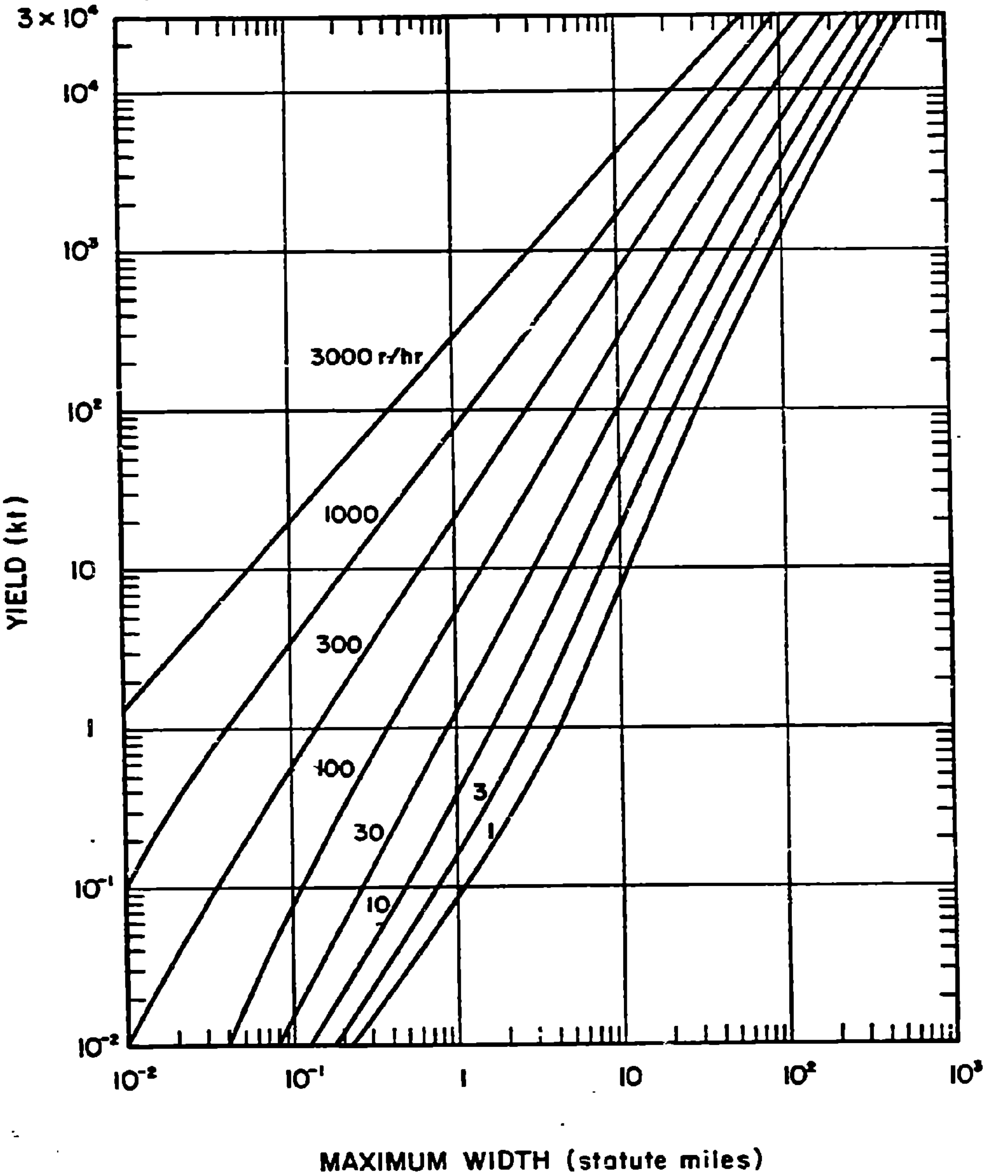


Figure 5-31. [redacted] Maximum Width as a Function of Yield, 10 Knot Effective Wind [redacted]

[redacted]

[redacted]

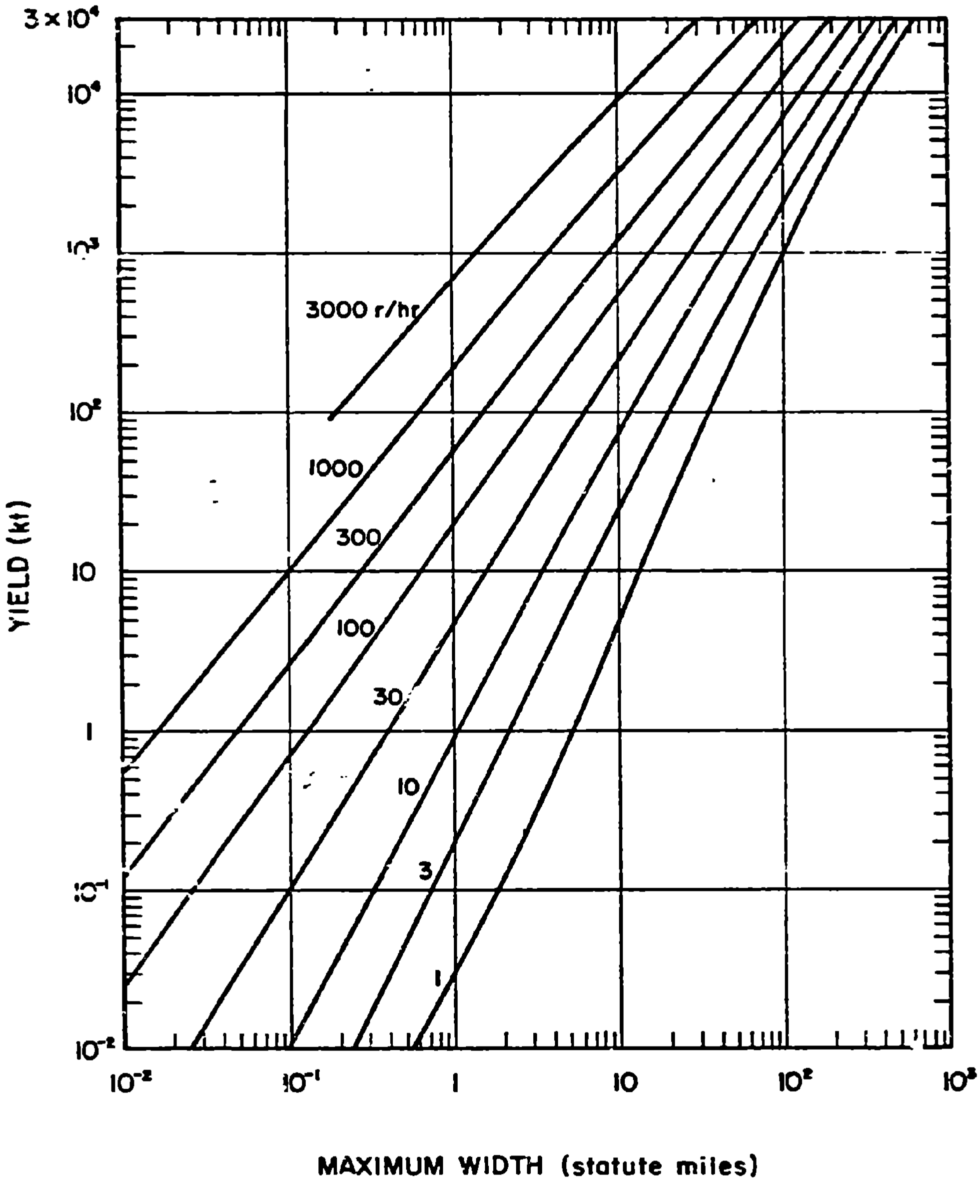


Figure 5-33. [redacted] Maximum Width as a Function of Yield, 40 Knot Effective Wind [redacted]

[redacted]

[redacted]

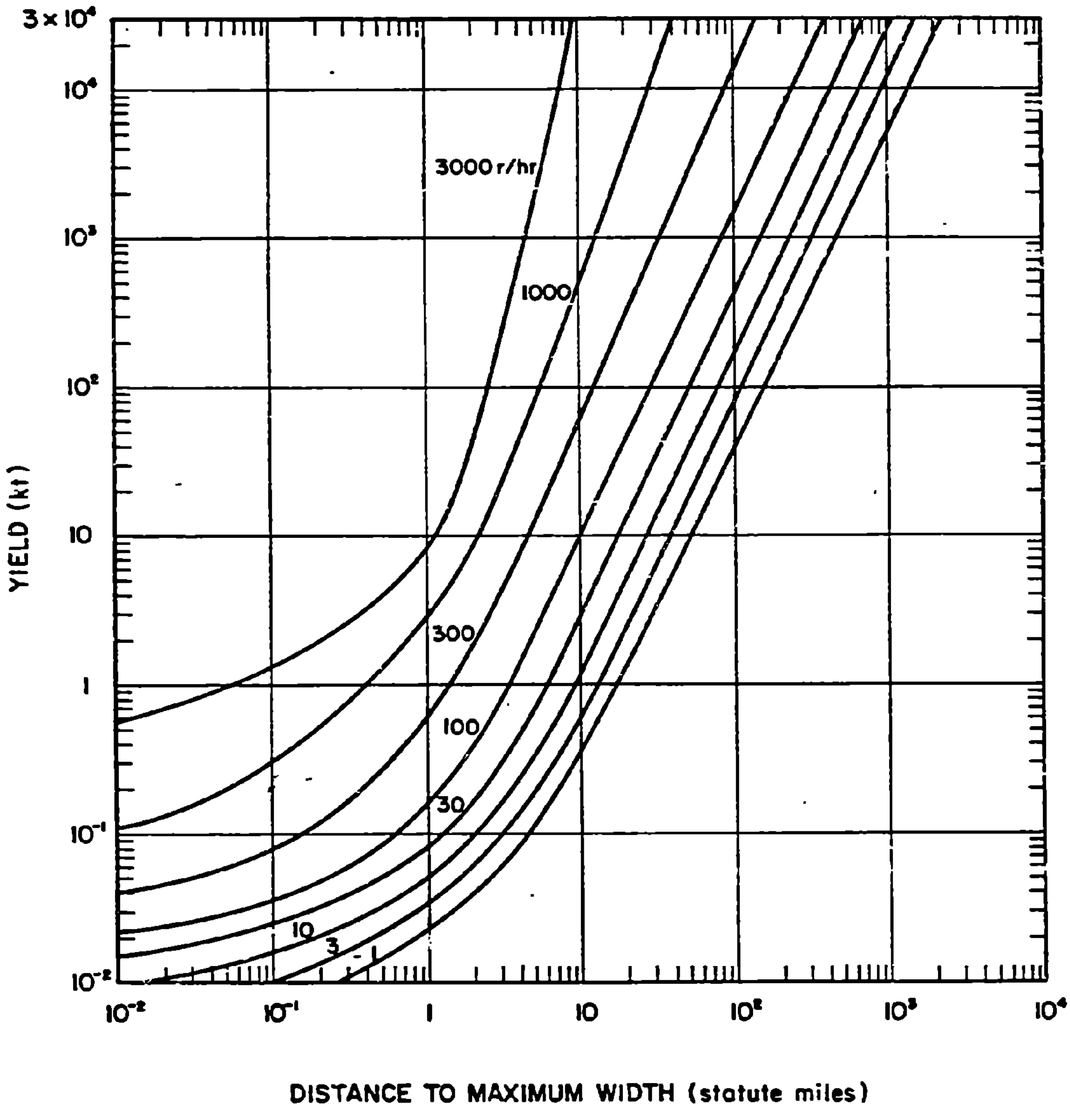


Figure 5-34. [redacted] Distance to Maximum Width as a Function of Yield, 10 Knot Effective Wind [redacted]

[redacted]

[redacted]

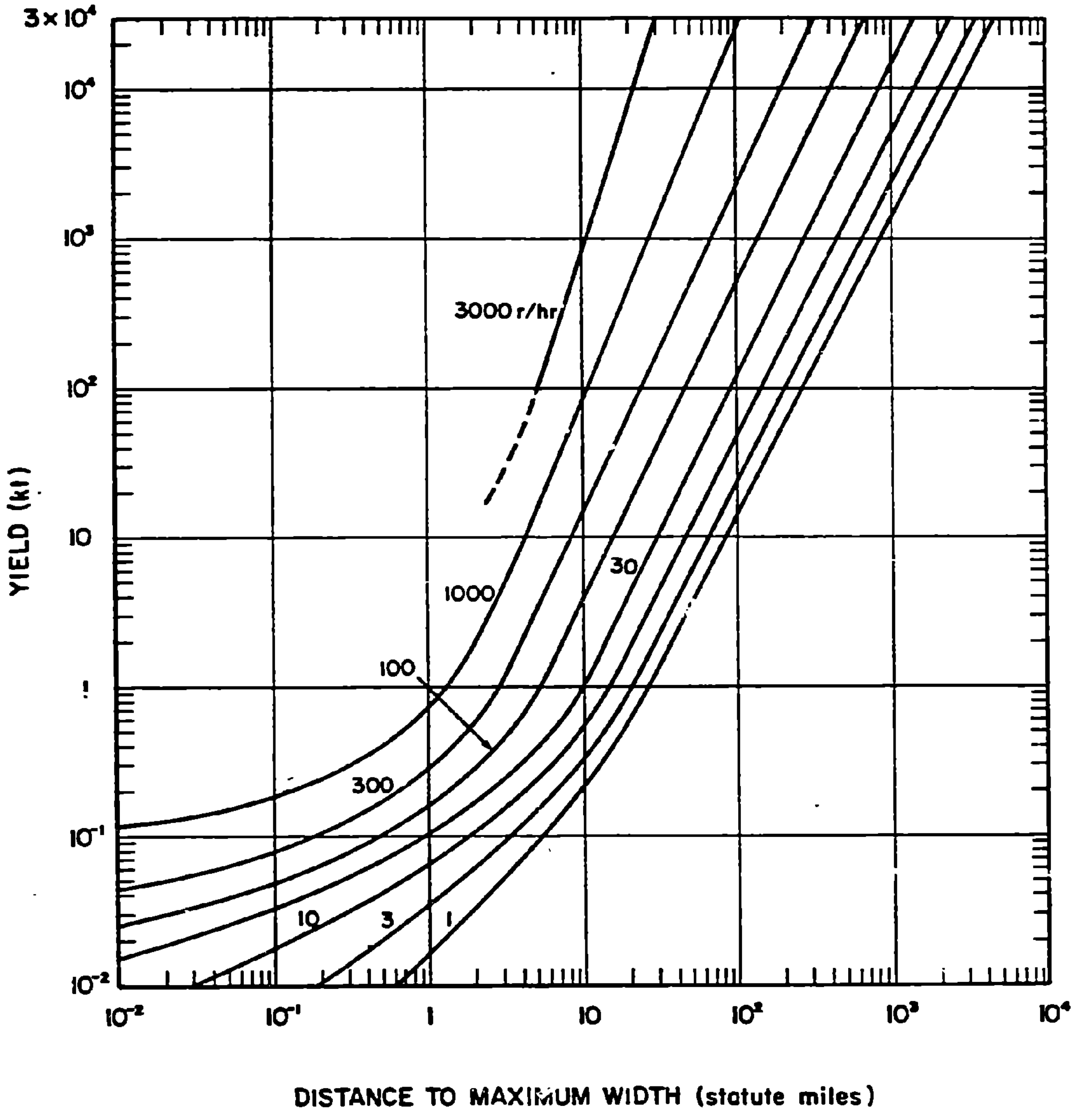


Figure 5-36. [redacted] Distance to Maximum Width as a Function of Yield, 40 Knot Effective Wind [redacted]

[redacted]

[redacted]

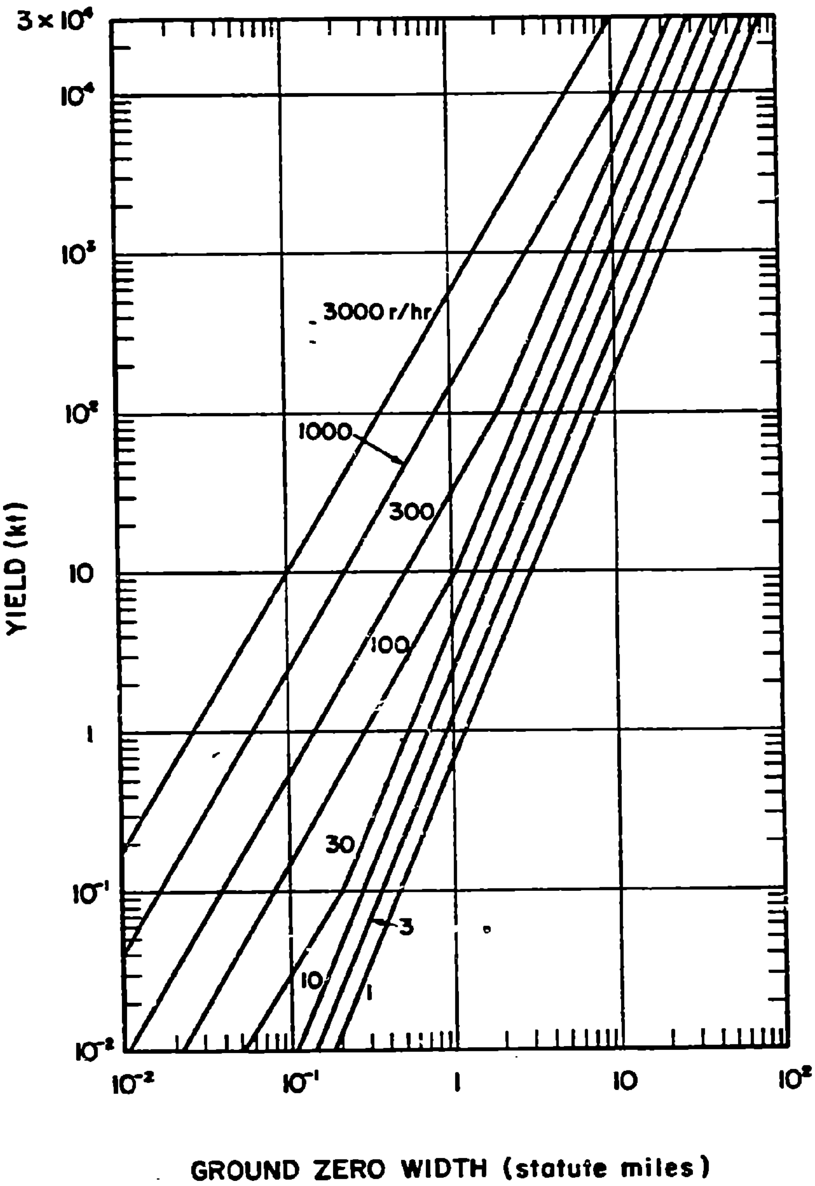


Figure 5-37. [redacted] Ground Zero Width as a Function of Yield [redacted]

[redacted]

Problem 5-12. Calculation of Fallout Gamma Radiation Dose Rate Contours for Bursts in the Transition Zone

[redacted] Figure 5-43 may be used to determine whether or not a burst is in the transition zone, i.e., below a height of burst of $100W^{0.35}$ feet. Burst heights below the curve in Figure 5-43 are in the transition zone. Burst heights above the curve are air bursts. In some situations, it may be desirable to consider bursts below $180W^{0.4}$ feet to be in the transition zone for conservative estimates. The means for doing this are discussed below. When a burst occurs in the transition zone, an approximation of the resulting fallout contamination patterns may be obtained by multiplying the dose rate contour values for a contact surface burst weapon of the same yield by an adjustment factor from Figure 5-44. The curves of Figure 5-44 were constructed under the assumption that the ratio of the dose rate values from a burst in the transition zone to the dose rate values for the same contour from a surface burst are proportional to the ratio of the volume of a segment of a sphere intercepted by the ground surface to the volume of the hemisphere, where the radius of the sphere is $100W^{0.35}$ feet, i.e.,

$$\text{Adjustment Factor} = \frac{\left(100 - \frac{h}{W^{0.35}}\right)^2 \left(200 + \frac{h}{W^{0.35}}\right)}{2 \times 10^6},$$

where h is the actual height of burst in feet, and W is the total weapon yield in kilotons.

[redacted] In view of the lack of data from bursts in the transition zone over a land surface, a more conservative estimate may be desired. In this case, the height of burst for the upper limit of the transition zone is taken to be $180W^{0.4}$ feet. The adjustment factor to be applied to dose rate values for the same contours from a surface burst of the same yield can be calculated from:

$$\text{Adjustment Factor} = \frac{\left(180 - \frac{h}{W^{0.4}}\right)^2 \left(360 + \frac{h}{W^{0.4}}\right)}{1.17 \times 10^7}.$$

[redacted] *Example* [redacted]

Given: A hypothetical weapon with a total yield of 600 kt, of which 200 kt results from fission, is burst 560 feet over a land surface with 10 knot effective wind conditions.

Find: The contour parameters for a dose rate of 15 rads/hr at $H + 1$ hour reference time over smooth terrain.

Solution: From Figure 5-43, a 600 kt weapon burst below about 940 feet would be in the transition zone. A height of burst of 560 feet is less than three quarters of the limiting altitude of the transition, so fallout is the only residual radiation to be considered. The 15 rads/hr contour for a fission yield to total yield ratio of 200/600 = 1/3 corresponds to the contour for 15 ÷ 1/3 = 45 rads/hr for a weapon of 600 kt fission yield. The dose rate over reasonably level terrain is about 70 percent of that over an ideal smooth plane. Thus, the ideal smooth plane contour parameters for this weapon burst on the surface would correspond to

$$\frac{45}{0.7} = 64 \text{ rads/hr}.$$

From Figure 5-44 (or from the normal adjustment factor equation given above) the height of burst adjustment factor for a 600 kt weapon burst at 560 feet is 0.21. Therefore, the desired contour parameters can be obtained by entering Figures 5-28, 5-31, 5-34, and 5-37 with a yield of 600 kt and reading the parameter values corresponding to an $H + 1$ hour dose rate of

$$\frac{64}{0.21} = 300 \text{ rads/hr}.$$

[redacted]

[redacted]

spheric humidity introduces further irregularities in fallout patterns. Also, because water surface burst particles take longer to fall than particles from land surface bursts, wind and weather conditions are more likely to change during the time of fallout transport and deposition. It is often difficult to define a downwind direction in the fallout pattern. The apparent downwind direction may vary with yield and with time after burst at which the pattern is observed or calculated.

[redacted] In almost all cases, the region of maximum deposit intensity is not around surface zero but considerably downwind. Thus, for a 10 Mt burst, the calculated region of a normalized dose rate of at least 300 r/hr at 1 hour extends from about 125 to 300 miles from surface zero. The dose rate would, of course, be much lower at the time of arrival and would vary throughout the area as a result of varying arrival times.

[redacted] As material in the cloud rises, it cools by entraining ambient air, and by expanding with increasing altitude. Fallout particles form by condensation of vapor and grow by coagulation; that is, by collision and adhesion of smaller particles to form larger particles. The vapor condensation may be considered a 3-stage process.

[redacted] In the first stage, calcium and magnesium from the sea water and iron, and other metals from the weapon condense as oxides. In the second stage sodium chloride, which is about 90 percent of dried sea salt, condenses on the nuclei provided by the stage 1 particles. In the third stage, water vapor condenses to liquid water or to ice, on the stage 2 particles.

[redacted] The median diameter of the stage 1 particles is about 1 micron contrasted to a few hundred microns for a land surface burst. The size is expected to increase slightly with yield, because the particles are formed by diffusion onto nuclei while the fireball is cooling by thermal radiation. The larger the fireball, the slower the cooling rate. The slower the cooling rate, the more time is available for diffusive growth.

[redacted] During and after the three condensation stages, coagulation causes particle growth. Particles of sub-micron size coagulate as a result of Brownian motion. Somewhat larger particles coagulate due to turbulent accelerations in the cloud. Turbulent coagulation only appears to be of importance in clouds from megaton bursts. Even larger particles grow by gravitational coagulation; that is, as they fall through the cloud they overtake and capture smaller particles. Gravitational coagulation is particularly important for low-yield bursts in humid atmospheres. The process is similar to one of the mechanisms for growth of ordinary raindrops. The largest particles formed, i.e., those from low yield bursts in a humid atmosphere, may have actual diameters of 2,000 microns. Particles of this size fall out of the cloud rapidly. Thus, there is a practical limit on the growth of particles in the cloud.

[redacted] Moisture effects play a dominant part in water surface burst fallout. In general, the more humid the atmosphere, the more radioactivity is deposited as close-in fallout. Most of the moisture contained in the clouds of low yield bursts comes from entrained air. Consequently, the higher the humidity, the greater the cloud moisture content. In turn, the salt particles absorb more water, and, as they get larger, gravitational coagulation proceeds faster.

[redacted] Moisture not only has a direct effect on particle formation, but also has an indirect effect on cloud height. The top of the cloud from a 20 kt water surface burst in a very humid tropical atmosphere may reach the tropopause at about 55,000 feet. In a less humid atmosphere, the cloud from a burst of the same yield may rise less than half as high (see Figure 5-39). Salt particles absorb moisture from humid air; the moisture evaporates when the particles are exposed to relatively dry air. Consequently the

[redacted]

[redacted] size, falling rate, and time and place of deposit of water surface burst fallout particles vary with the atmospheric humidity the particles encounter during their trajectories. As the particles fall, they usually shrink by evaporation and may become completely dry, with a diameter of at most 100 to 200 microns. They then fall very slowly, and move large horizontal distances as a result of the forces exerted by the wind. Finally, the particles reach the more humid air near sea level, begin to grow by absorbing moisture, and fall faster. Thus, although particles from a megaton burst may leave the cloud with a water content almost entirely derived from sea water, this water may evaporate completely during fall, and the water content of the particles that reach the surface is entirely atmospheric moisture. An exception to this situation could occur for a burst in an arctic atmosphere. The cold air retards evaporation, even if humidity is low, and some of the original sea water could remain on the particles.

[redacted] Maximum fallout intensity, as well as the area covered by fallout from a water surface burst increases with weapon yield. For yields between 1 kt and 100 kt, the normalized $H + 1$ hour exposure rates are expected to be negligible. The highest normalized intensities from a 100 kt explosion are expected to be more than 50 roentgens per hour (r/hr), but less than 100 r/hr. The highest intensities from a 1 Mt burst are expected to be over 100 r/hr but less than 300 r/hr. Finally, a 10 Mt burst is expected to produce intensities over 300 r/hr, but less than 1,000 r/hr. Since all of these exposure intensities are normalized to $H + 1$ hour, and the fallout will arrive at significantly longer times after burst for the larger yields (depending upon the wind), the radioactivity will have decayed to much smaller levels prior to the time of arrival and fallout generally is not expected to be a governing effect from water surface bursts.

5-26 Underwater Bursts [redacted]

[redacted] An underwater burst creates a highly energetic bubble, whose history determines the major above-surface effects. For very shallow explosions, the bubble expands through the water surface with a high internal pressure, and develops a hollow column through which the bubble blows out into the atmosphere in the form of a cloud at the column top. For a somewhat greater depth, the bubble expands through the water surface at lower internal pressure and a column again forms, but no blowout occurs. Transition from columnar formations to plume-like eruptions, hemispherical in shape, takes place as the depth increases. The migration of the underwater bubble through the surface near its minimal phase at or shortly after its maximum-expansion phase creates the plumes. For deep explosions, the bubble may experience several oscillations as it migrates upwards. If the explosion is very deep, the bubble will degenerate and break up before reaching the surface. It is possible that an explosion may take place at such a great depth that little, if any, disturbance will be noted on the surface.

[redacted] The ejected water, whether a column or a plume, will fall back to the surface rapidly. This massive subsidence creates a radially expanding aerosol cloud, or base surge, at the water surface. The base surge expands as a ring or disk until it dissipates energy received from the subsidiary plumes or columns. After expanding, it drifts with the surface winds. Some evidence suggests the base surge has the same initial bulk density as that of the plumes or columns from which it is formed, being several times the density of air. As it travels downwind, it will react to the existing atmospheric conditions; e.g., evaporating or developing into low-cloud formations. These physical phenomena are described in more detail in Section IV, Chapter 2.

[redacted] Three sources of radioactivity are the

[redacted]

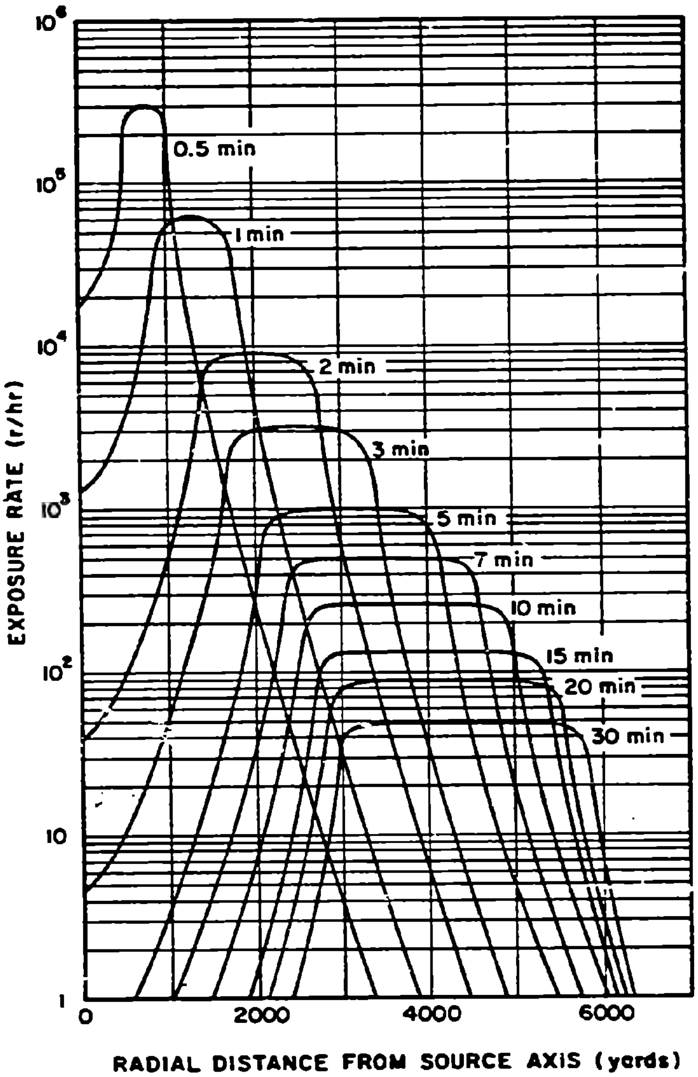


Figure 5-46. [redacted] Base Surge Radiation Exposure Rate 15 Feet Above the Water Surface from a 10 kt Explosion at a Depth of 65 Feet in 5,000 Feet of Water, No-Wind Environment [redacted]

[redacted]

[redacted]

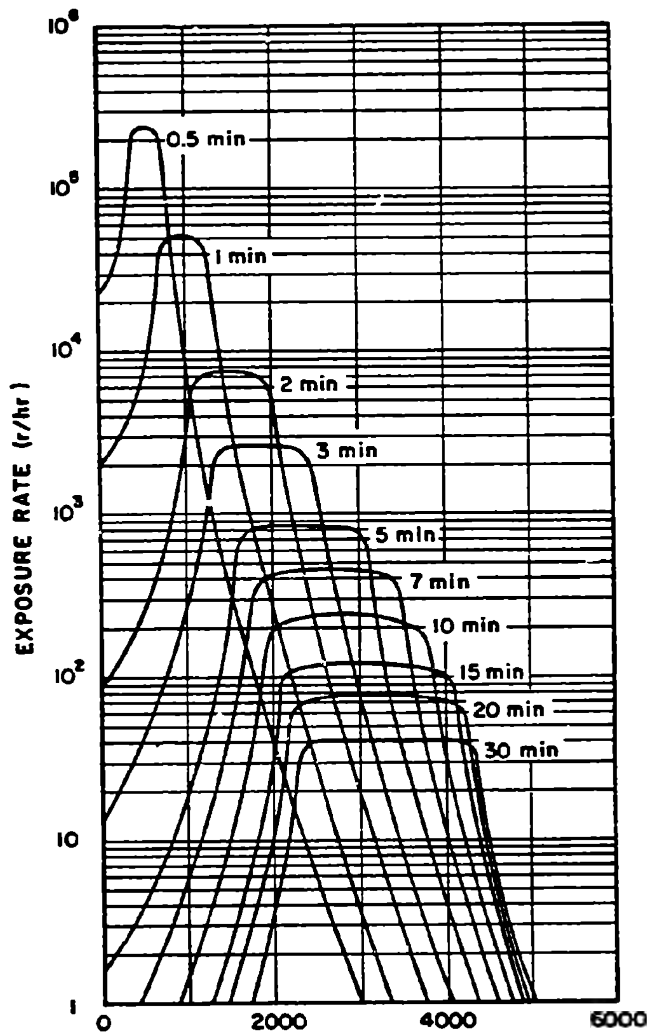


Figure 5-47. [redacted] Base Surge Radiation Exposure Rate 15 Feet Above the Water Surface from a 10 kt Explosion on the Bottom in 65 Feet of Water, No-Wind Environment [redacted]

[redacted]

[redacted]

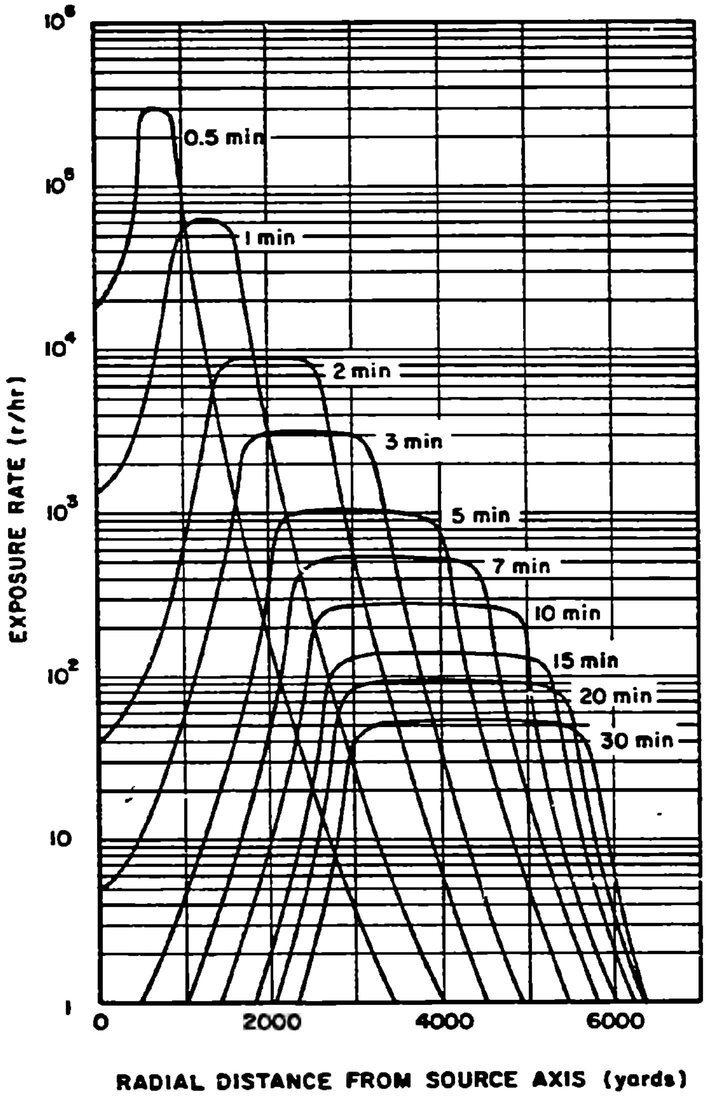


Figure 5-48. [redacted] Base Surge Radiation Exposure Rate 15 Feet Above the Water Surface from a 10 kt Explosion at a Depth of 150 Feet in 5,000 Feet of Water, No-Wind Environment [redacted]

[redacted]

[redacted]

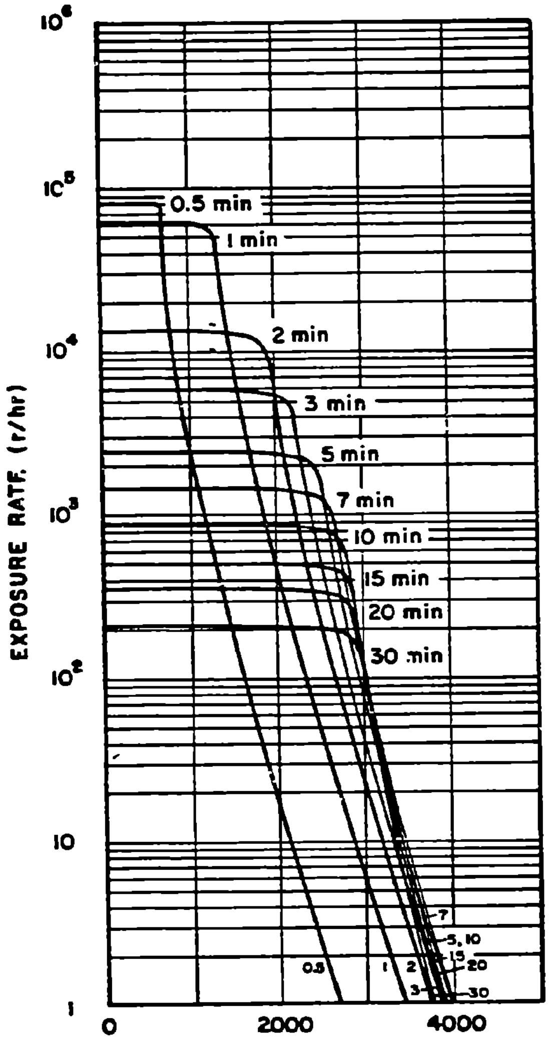


Figure 5-49. [redacted] Base Surge Radiation Exposure Rate 15 Feet Above the Water Surface from a 10 kt Explosion at a Depth of 500 Feet in 5,000 Feet of Water, No-Wind Environment [redacted]

[redacted]

[redacted]

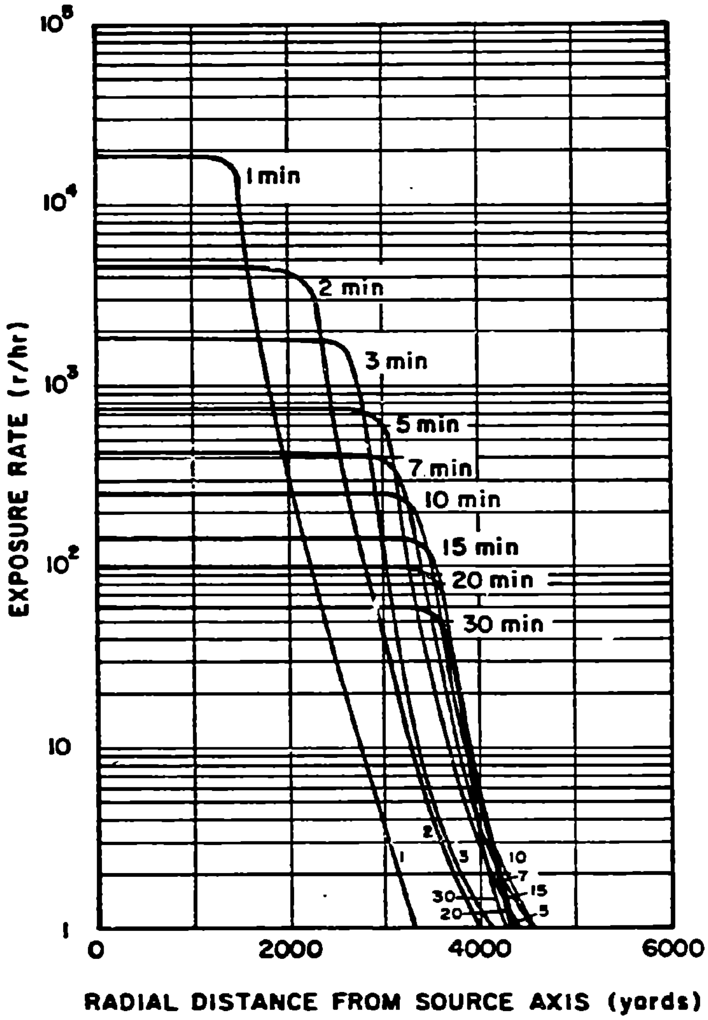


Figure 5-50. [redacted] Base Surge Radiation Exposure Rate 15 Feet Above the Water Surface from a 10 kt Explosion at a Depth of 1,000 Feet in 5,000 Feet of Water, No-Wind Environment [redacted]

[redacted]

[redacted]

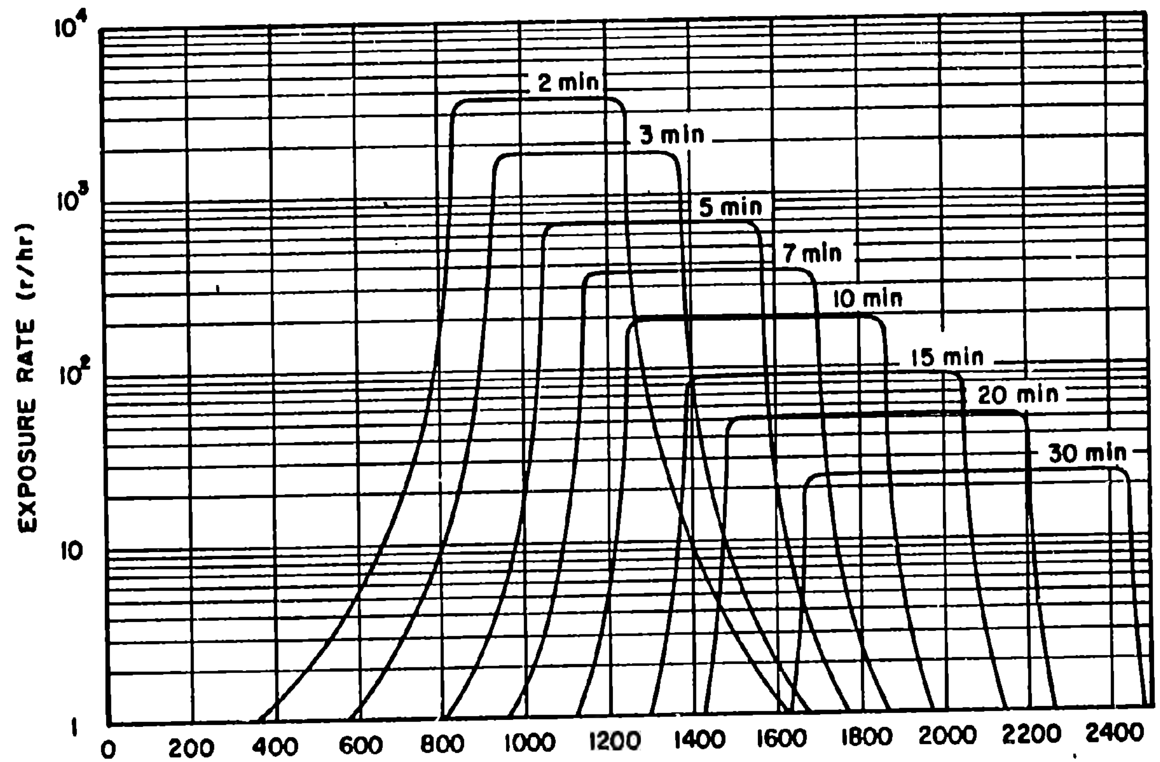


Figure 5-52. [redacted] Pool Radiation Exposure Rate 15 Feet Above the Water Surface from a 10 kt Explosion at a Depth of 65 Feet in 5,000 Feet of Water, No-Current Environment [redacted]

[redacted]

[redacted]

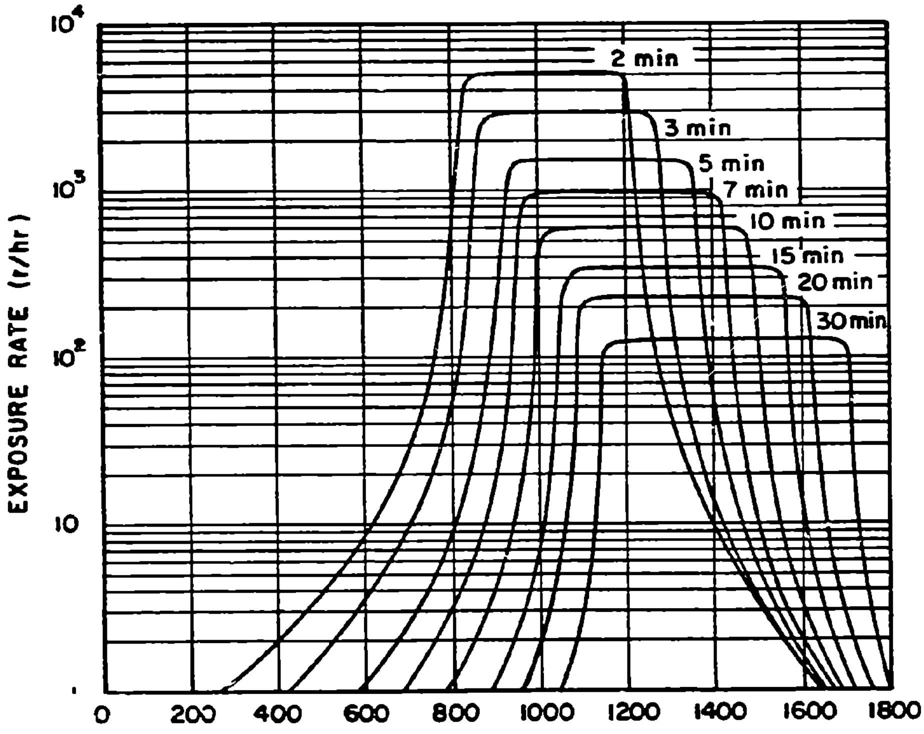


Figure 5-53. [redacted] Pool Radiation Exposure Rate 15 Feet Above the Water Surface from a 10 kt Explosion on the Bottom in 65 Feet of Water, No-Current Environment [redacted]

[redacted]

[redacted]

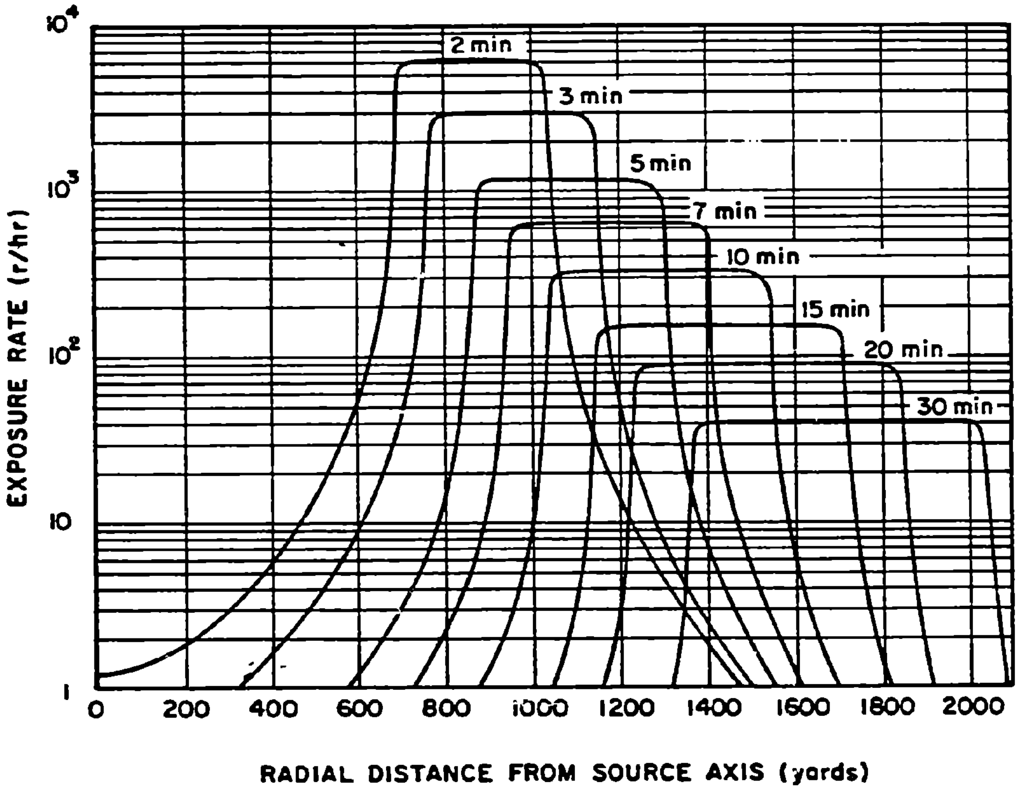


Figure 5-54. [redacted] Pool Radiation Exposure Rate 15 Feet Above the Water Surface from a 10 kt Explosion at a Depth of 150 Feet in 5,000 Feet of Water, No-Current Environment [redacted]

[redacted]

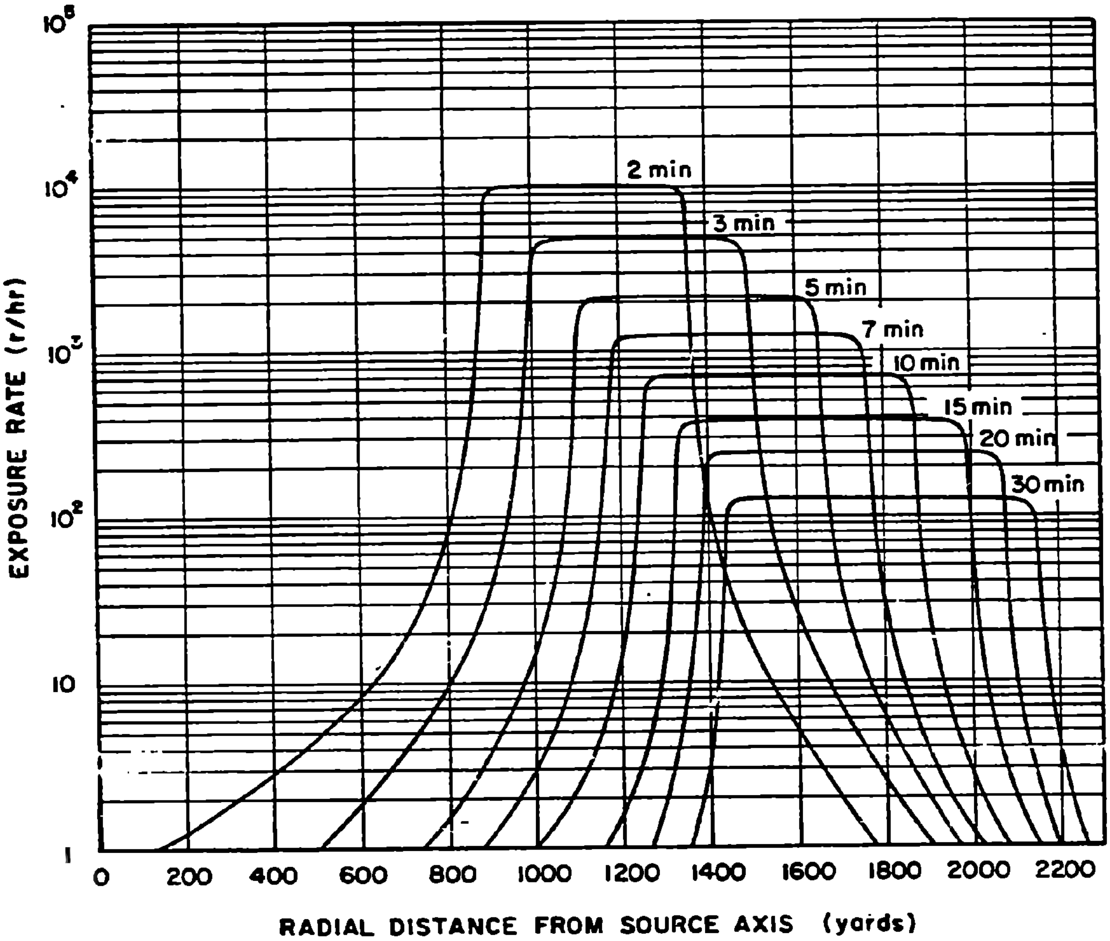


Figure 5-55. [redacted] Pool Radiation Exposure Rate 15 Feet Above the Water Surface from a 10 kt Explosion at a Depth of 500 Feet in 5,000 Feet of Water, No-Current Environment [redacted]

[redacted]

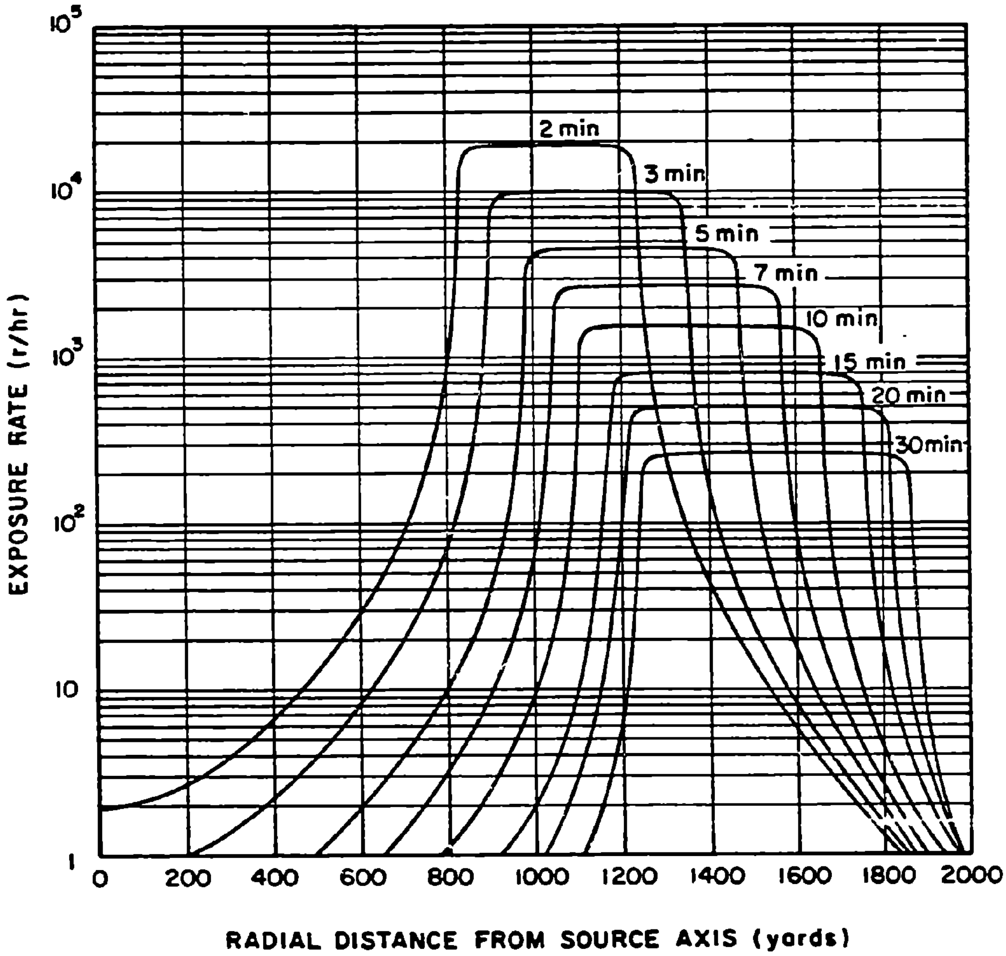


Figure 5-56. [redacted] Pool Radiation Exposure Rate 15 Feet Above the Water Surface from a 10 kt Explosion at a Depth of 1,000 Feet in 5,000 Feet of Water, No-Current Environment [redacted]

[redacted]

[redacted]

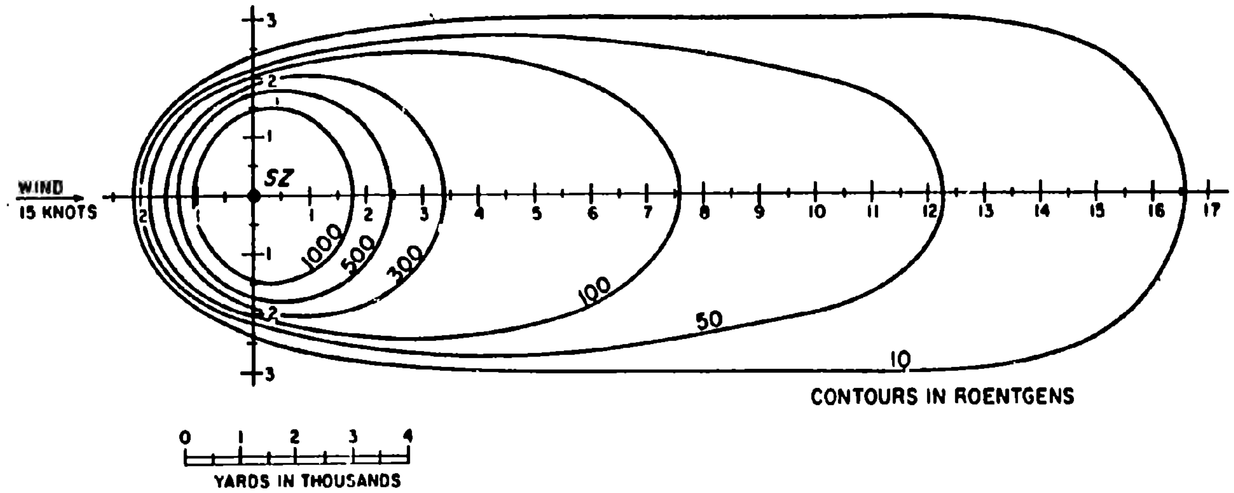


Figure 5-72. [redacted] Thirty-Minute Total Exposure 15 Feet Above the Water Surface from a 10 kt Explosion at a Depth of 500 Feet in 5,000 Feet of Water, 15 Knot Wind, No-Current Environment [redacted]

[redacted]

[redacted]

[redacted]

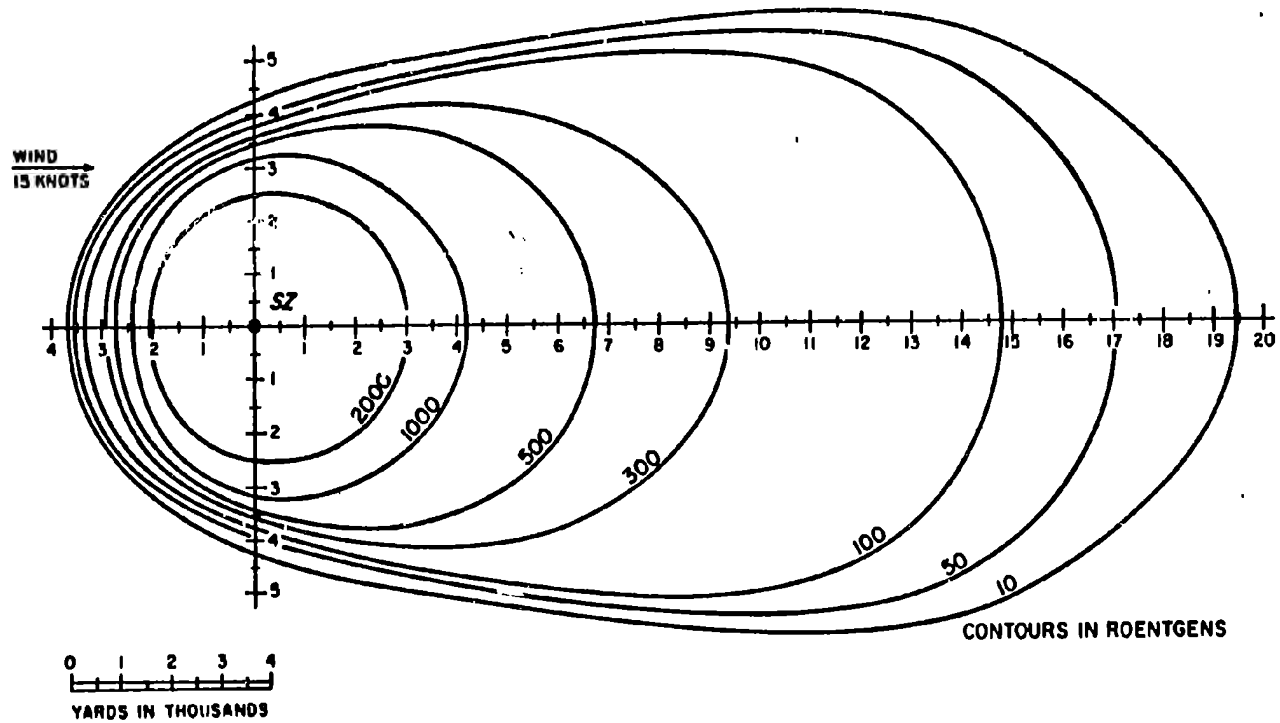


Figure 5-75. [redacted] Thirty-Minute Total Exposure 15 Feet Above the Water Surface from a 100 kt Explosion at a Depth of 890 Feet in 5,000 Feet of Water, 15 Knot Wind, No-Current Environment [redacted]

[redacted]

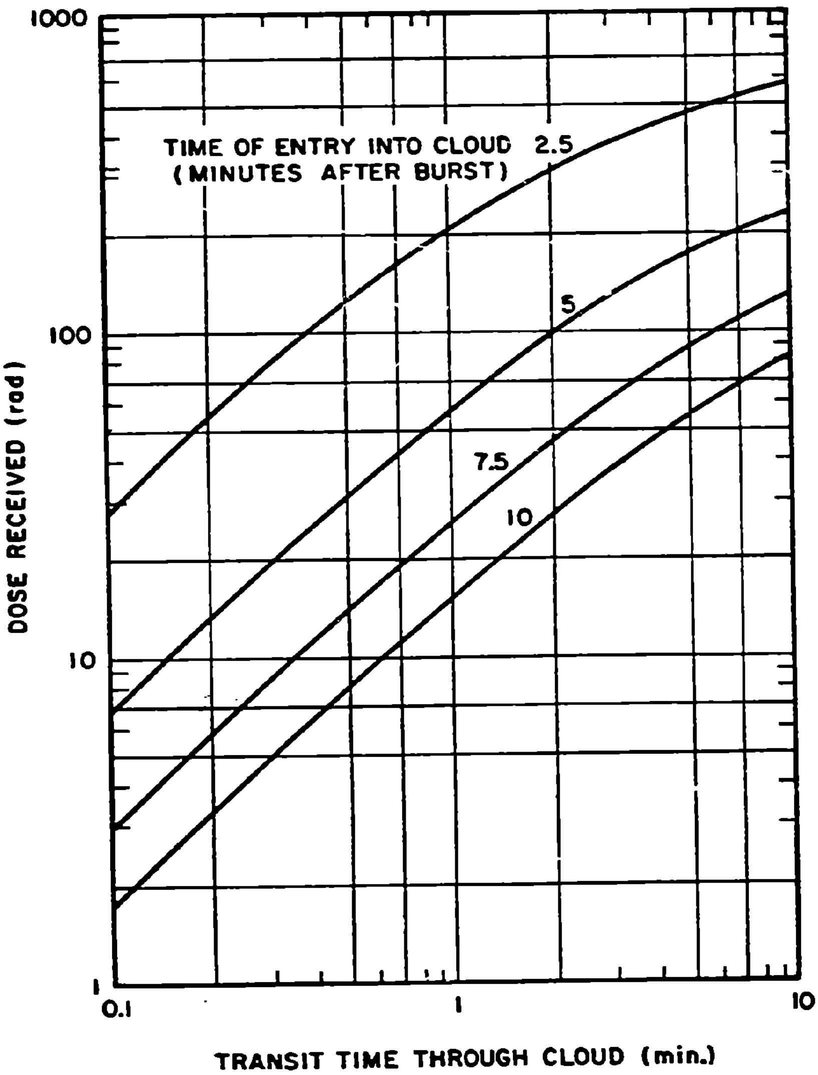


Figure 5-79. [redacted] Dose Received While Flying Through a Nuclear Cloud as a Function of Transit Time Through the Cloud [redacted]

[redacted]

[redacted] BIBLIOGRAPHY [redacted]

Baum, S., P. W. Wong, and P. J. Dolan, *NUCROM: A Model of Rainout from Nuclear Clouds*, DNA 3389F, Stanford Research Institute, Menlo Park, California, August 1974 [redacted]

Biggers, W. A., and K. C. Kohr, *Neutron Outputs from Selected LASL Nuclear Devices* [redacted] LA 3688, Los Alamos Scientific Laboratory, Los Alamos, New Mexico, April 1967 [redacted]

Beyster, J. R., et al., *Status of Neutron and Gamma Output from Nuclear Weapons* [redacted] SAI 70-205, DASA 2567, Science Applications Incorporated, La Jolla, California, May 1971 [redacted]

Bunney, L. R., and D. Sam, *Gamma-Ray Spectra of Fractionated Fission Products*, NOLTR 71-103, Naval Ordnance Laboratory, White Oak, Silver Spring, Maryland, 18 June 1971 [redacted]

Canu, J. F., and P. J. Dolan, *Prediction of Neutron Induced Activity in Soils* [redacted] Technical Analysis Report AFSWP 518, Headquarters, Armed Forces Special Weapons Project, Washington, D.C., 4 June 1957 [redacted]

Crawford, T. V., and K. R. Peterson, *BANEBERRY – Discussion of Diffusion Calculations Including Potential Exposure to Child's Thyroid from I-131 Via the Forage-Cow-Milk Pathway* [redacted] COPK 71-20, Lawrence Radiation Laboratory, Livermore, California, 3 March 1971 [redacted]

Crawford, T. V., *Precipitation Scavenging and 2BPUFF*, UOPKA 71-14, Lawrence Livermore Laboratory, Livermore, California, 6 December 1971 [redacted]

Crocker, G. R., *Fission Product Decay Chains: Schematics with Branching Fractions, Half-Lives, and Literature References*, USNRDL-TR-67-111, U.S. Naval Radiological Defense Laboratory, San Francisco, California, 24 June 1967 [redacted]

Crocker, G. R., and T. Turner, *Calculated Activities, Exposure Rates, and Gamma Spectra for Unfractionated Fission Products*, USNRDL-TR-1009, U.S. Naval Radiological Defense Laboratory, San Francisco, California, 28 December 1965 [redacted]

Crocker, G. R., and M. A. Connors, *Gamma-Emission Data for the Calculation of Exposure Rates from Nuclear Debris, Volume I, Fission Products*, USNRDL-TR-876, U.S. Naval Radiological Defense Laboratory, San Francisco, California, 10 June 1965 [redacted]

Crocker, G. R., J. D. O'Connor, and E. C. Freiling, *Physical and Radiochemical Properties of Fallout Particles*, NRDL-TR-899, Naval Radiological Defense Laboratory, San Francisco, California, 15 June 1965 [redacted]

Department of Defense Land Fallout Prediction System, DASA 1800-I through 1800-VII, Defense Atomic Support Agency, Washington, D.C.; U.S. Army Nuclear Defense Laboratory, Edgewood Arsenal, Maryland; U.S. Naval Radiological Defense Laboratory, San Francisco, California; Technical Operations Research, Burlington, Massachusetts; 1966 [redacted]

 [redacted]

[redacted]

[redacted]

Dolan, P. J., *Gamma Spectra of Uranium-235 Fission Products at Various Times After Fission,* AFSWP 524, Headquarters, Armed Forces Special Weapons Project, Washington, D.C., March 1959 [redacted]

Dolan, P. J., *Gamma Spectra of Uranium-238 Fission Products at Various Times After Fission,* DASA 526, Headquarters, Defense Atomic Support Agency, Washington, D.C., May 1959 [redacted]

Dolan, P. J., *Theoretical Dose Rate Decay Curves for Contamination Resulting from Land Surface Burst Nuclear Weapons* [redacted] DASA 528, Defense Atomic Support Agency, Washington, D.C., 6 August 1959 [redacted]

Englemann, R. J., and W. G. N. Slinn, *Precipitation Scavenging (1970),* AEC Symposium Series, U.S. Atomic Energy Commission, Washington, D.C., 22 December 1970 [redacted]

Englemann, R. J., *Priorities in Scavenging Research,* AEC Symposium Series U.S. Atomic Energy Commission, Washington, D.C., 22 December 1970 [redacted]

French, R. L., *A First-Last Collision Model of the Air/Ground Interface Effects on Fast-Neutron Distributions, Nucl. Sci. Engr., 19,* 151-157, 1964 [redacted]

Freiling, E. C., and N. E. Ballou, *Nature of Nuclear Debris in Sea Water, Nature 195,* No. 4848, pp. 1283-1287, 29 September 1962 [redacted]

Fritzsche, A. E., N. E. Lorimier, and Z. G. Burson, *Measured Low-Altitude Neutron and Gamma Dose Distributions Due to a 14-MeV Neutron Source, EGG 1183-1449, E. G., and G., Inc., 1969* [redacted]

Fritzsche, A. E., N. E. Lorimier, and Z. G. Burson, *Measured High-Altitude Neutron and Gamma Dose Distributions Due to a 14-MeV Neutron Source,* EGG 1183-1438, E. G., and G., Inc., 1969 [redacted]

Harris, R. J., Jr., et al., *Models of Radiation in Air – The ATR Code,* DNA 2803I, SAI-71-557-LV, Science Applications Incorporated, La Jolla, California, May 1972 [redacted]

Huebsch, I. O., *Fallout Predictions for Water-Surface Nuclear Bursts,* USNRDL-TR-67-147, U.S. Naval Radiological Defense Laboratory, San Francisco, California, 28 November 1967 [redacted]

Heubsch, I. O., *Development of a Water-Surface-Burst Fallout Model: The Formation, Dispersion and Deposition of Fallout Particles,* USNRDL Technical Report, U.S. Naval Radiological Defense Laboratory, San Francisco, California [redacted]

Keith, J. R., and F. H. Shelton, *Neutron Transport in Non-Uniform Air by Monte Carlo Calculation, Volume I,* DASA 2236-I KN-774-69-1, Kaman Nuclear, Colorado Springs, Colorado, 15 January 1969 [redacted]

[redacted]

[redacted]

[redacted]

Keith, J. R., and F. H. Shelton, *Neutron Transport in Non-Uniform Air by Monte Carlo Calculation* [redacted] Volume II, KN-774-69-1, DASA 2236-II, Kaman Nuclear, Colorado Springs, Colorado, 15 January 196[redacted]

Knox, J. G., and A. L. Williams, *Rainout Studies at Lawrence Livermore Laboratory,* UCRL 51530, Lawrence Livermore Laboratory, University of California/Livermore, Livermore, California, 11 February 197[redacted]

Krey, P. W., et al., *Soil Activation by Neutrons* [redacted] Project 2.1, WT-1410, U.S. Army Chemical Warfare Laboratories, Army Chemical Center, Maryland, 16 May 1960 [redacted]

Lee, H., P. W. Wong, and S. L. Brown, SEER II: *A New Damage Assessment Fallout Model,* DNA 3008F, Stanford Research Institute, Menlo Park, California, May 1972 [redacted]

Marshall, J. D., and M. B. Wells, *The Effects of Cut-Off Energy on Monte Carlo Calculated Gamma-Ray Dose Rates in Air,* RRA-M67, Radiation Research Associates, Fort Worth, Texas, 1966 [redacted]

Mooney, L. G., and R. L. French, *Improved Models for Predicting Nuclear Weapon Initial Radiation Environments* [redacted]. RRA-T93, DASA 2615, Radiation Research Associates, Fort Worth, Texas, 31 December 196[redacted]

Norment, H. G., and E. J. Tichovolsky, *A New Fallout Transport Code for the DELFIC System: The Diffusive Transport Module,* DASA 2669, Arcon Corporation, Wakefield, Massachusetts, 1 March 1971 [redacted]

Norment, H. G., *A Precipitation Scavenging Model for Studies of Tactical Nuclear Operations, Volume I – Theory and Preliminary Results, Volume II – The DELFIC-PSM Code,* DNA 3661F-1, -2, Mt. Auburn Research Associates, Inc., Newton, Massachusetts, 18 June 1975 [redacted]

Read, P. A., *Neutron Induced Activity on a Beach: A Method for Calculating the Dose Rate,* USNRDL-TR-67-133, U.S. Naval Radiological Defense Laboratory, San Francisco, California, 27 October 1967 [redacted]

Ritchie, R. H., and V. E. Anderson, *Some Monte Carlo Results on the Penetration of Neutrons from Weapons in an Air-Over-Ground Geometry* [redacted] ORNL-3116, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 26 July 1962 [redacted]

Schuert, E. A., *Distribution of the Radioactive Debris and Associated Nuclear Radiation from Underwater Nuclear Explosions* [redacted] USNRDL-TR-67-28, DASA 1240, Part I, Chapter 11, U.S. Naval Radiological Defense Laboratory, San Francisco, California, 15 December 1966 [redacted]

[redacted]

[redacted]

[redacted]

Selph, W. E., and M. B. Wells, *Weapons Radiation Shielding Handbook. Chapter 6, Methods for Predicting Radiation Fields Produced by Nuclear Weapons* [redacted] DASA-1892-4, Oak Ridge National Laboratory, Oak Ridge, Tennessee, December 1969 [redacted]

Shelton, F. H., *Nuclear Weapons as Neutron Sources, The Neutron Environments They Produce, and Some Neutron Effects on Aerospace Systems* [redacted] DASA-2383-1, Volume I, Neutron Sources, KN 774-69-6, Kaman Nuclear, Colorado Springs, Colorado, October 1969 [redacted]

Shelton, F. H., and J. R. Keith, *Nuclear Weapons as Neutron Sources, The Neutron Environments They Produce, and Some Neutron Effects on Aerospace Systems* [redacted] *Volume II, Neutron Environments and Some Effects*, DASA 2383-2, KN 774-69-6, October 1969 [redacted]

Slade, D. H. (Ed.), *Meteorology and Atomic Energy – 1968*, USAEC Report TID-24190, Environmental Science Services Administration, Washington, D.C., July 1968 [redacted]

Smith, R. J., R. F. Benck, and E. E. Lissak, *Initial Gamma Data from Nuclear Weapon Tests, 1948 Through 1962* [redacted] NDL-TR-53, U.S. Army Nuclear Defense Laboratory, Edgewood Arsenal, Maryland, July 1965 [redacted]

Snay, H. G., *The Hydrodynamic Background of the Radiological Effects of Underwater Nuclear Explosions* [redacted] Proceedings of the Tripartite Symposium on the Technical Status of Radiological Defense in the Fleets, U.S. Naval Radiological Defense Laboratory, San Francisco, California, 16-20 May 1960, Vol. II, USNRDL Reviews and Lectures, No. 103 [redacted]

Stensland, G. J., *Further Numerical Model Studies of the Washout of Hygroscopic Particles in the Atmosphere*, UCRL-51614, Lawrence Radiation Laboratory, University of California/Livermore, Livermore, California, 2 July 1974 [redacted]

Straker, E. A., *Time-Dependent Neutron and Secondary Gamma-Ray Transport in an Air-Over-Ground Geometry, Volume II. Tabulated Data*, ORNL 4289, Vol. II, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September 1968 [redacted]

Williams, A. L., *Rain Scavenging of Radioactive Particles*, UCRL-517765, Lawrence Radiation Laboratory, University of California/Livermore, Livermore, California, 28 February 1975 [redacted]

Wong, P. W., and H. Lee, *Utilization of the SEER Fallout Model in a Damage Assessment Computer Program (DACOMP)*, DNA 3608F, Stanford Research Institute, Menlo Park, California, 27 February 1975 [redacted]

Young, F. H., et al., *The Radiological Effects from Underwater Nuclear Explosions* [redacted] USNRDL-TR-68-1, U.S. Naval Radiological Defense Laboratory, San Francisco, California, 17 October 1967 [redacted]

[redacted]

The Effects of Atomic Weapons

PREPARED FOR AND IN COOPERATION WITH THE U. S. DEPARTMENT OF DEFENSE AND THE U. S. ATOMIC ENERGY COMMISSION

Under the direction of the

LOS ALAMOS SCIENTIFIC LABORATORY

LOS ALAMOS, NEW MEXICO

Revised September 1950

BOARD OF EDITORS

J. O. HIRSCHFELDER, *Chairman*

DAVID B. PARKER

ARNOLD KRAMISH

RALPH CARLISLE SMITH

SAMUEL GLASSTONE, *Executive Editor*

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price $1.25 (paper bound)

CHAPTER I[1]

PRINCIPLES OF AN ATOMIC EXPLOSION

A. INTRODUCTION

Characteristics of an Atomic Explosion

1.1 The atomic bomb is a new weapon of great destructive power. It resembles bombs of the more conventional type in so far as its explosive effect is the result of the very rapid liberation of a large quantity of energy in a relatively small space. But it differs from other bombs in three important respects: first, the amount of energy released by an atomic bomb is a thousand or more times as great as that produced by the most powerful TNT bombs; second, the explosion of the bomb is accompanied by highly-penetrating, and deleterious, invisible rays, in addition to intense heat and light; and third, the substances which remain after the explosion are radioactive, emitting radiations capable of producing harmful consequences in living organisms. It is on account of these differences that the effects of the atomic bomb require special consideration.

1.2 A knowledge and understanding of the mechanical and radiation phenomena associated with an atomic explosion are of vital importance. The information may be utilized, on the one hand, by architects and engineers in the design of structures; while on the other hand, those responsible for civil defense, including treatment of the injured, can make preparations to deal with the emergencies that may arise from an atomic explosion.

1.3 During World War II many large cities in England, Germany, and Japan were subjected to terrific attacks by high-explosive and incendiary bombs. Yet, when proper steps had been taken for the protection of the civilian population and for the restoration of services after the bombing, there was little, if any, evidence of panic. It is the purpose of this book to state the facts concerning the atomic bomb, and to make an objective, scientific analysis of these facts. It is hoped that as a result, although it may not be feasible completely to allay fear, it will at least be possible to avoid panic.

[1] Material contributed by G. Gamow, S. Glasstone, J. O. Hirschfelder.

8.90 Apart from the effect of the base surge, radioactive contamination will result from the rain produced by the fall-out. There has been some difference of opinion concerning the relative contributions of the base surge and the fall-out to the total radiation dosage. The question is of practical significance, since some protection of personnel from ordinary rainfall, as from the fall-out, is possible in the open. But since the base surge is a cloud which moves laterally, protection from its radiation is not so simple. There is no doubt that at Bikini, the base surge was very significant, and it appears that, in general, both base surge and fall-out will contribute to the radiation dosage, the relative amounts depending on the depth of burst, depth of water, and other conditions.

8.91 From measurements made at the time of the Bikini "Baker" test, it has been possible to draw some general conclusions with regard to the integrated or total radiation dosage received at various distances from surface zero. Actually, about 90 percent of this dosage was attained within 30 minutes of the explosion. The results are represented in the form of radiation dosage contours in Figs. 8.91a,

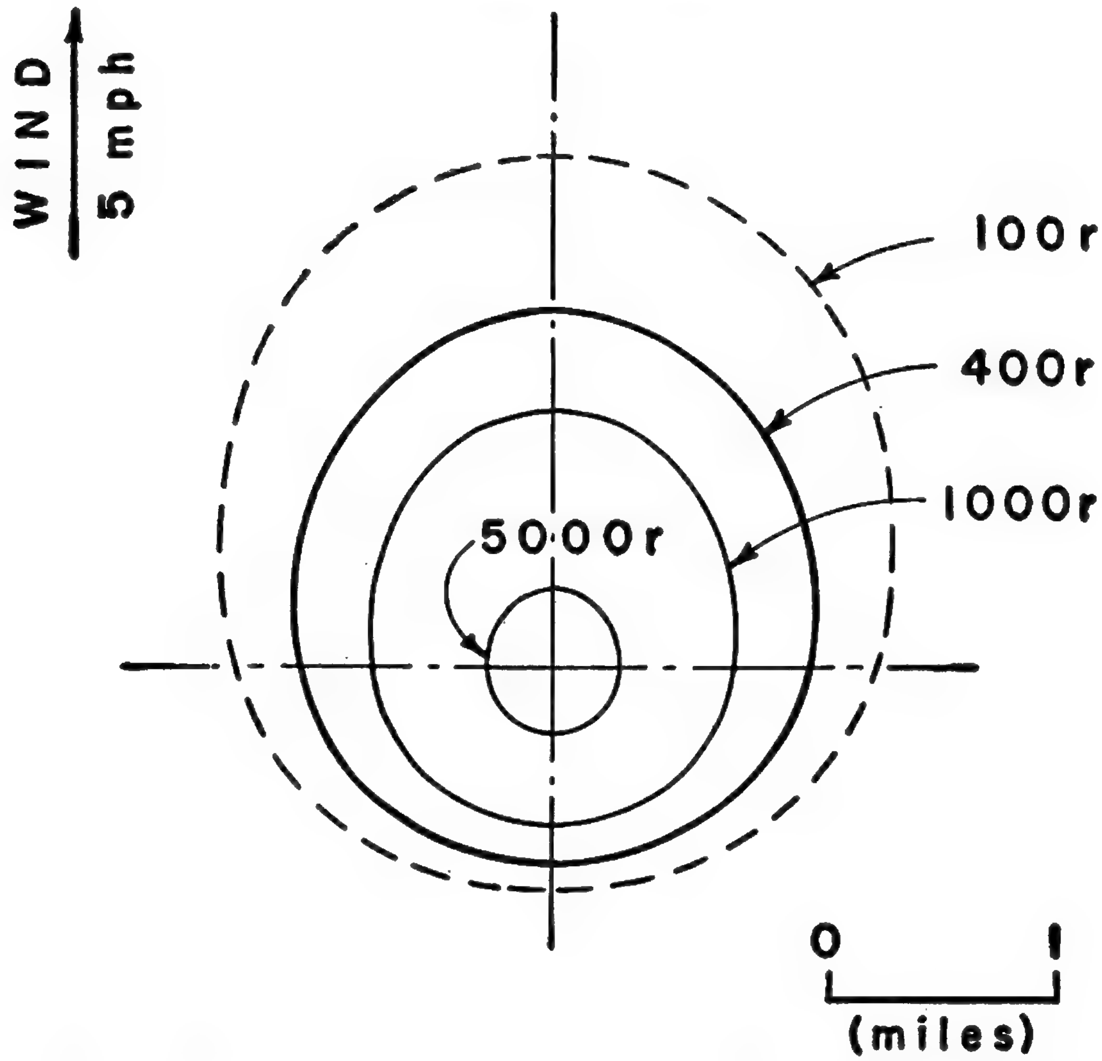


Figure 8.91a. Contours for various integrated radiation dosages due to base surge from underwater burst.

b, and c. The dosage due to the base surge mist as it passes over and through an area is shown in Fig. 8.91a. The distortion from symmetry is due to the fact that a wind of about 5 miles per hour was blowing at and near the surface of the lagoon at the time of the detonation. This results, of course, in the radioactive contamination extending much further downwind than in the upwind direction.[19]

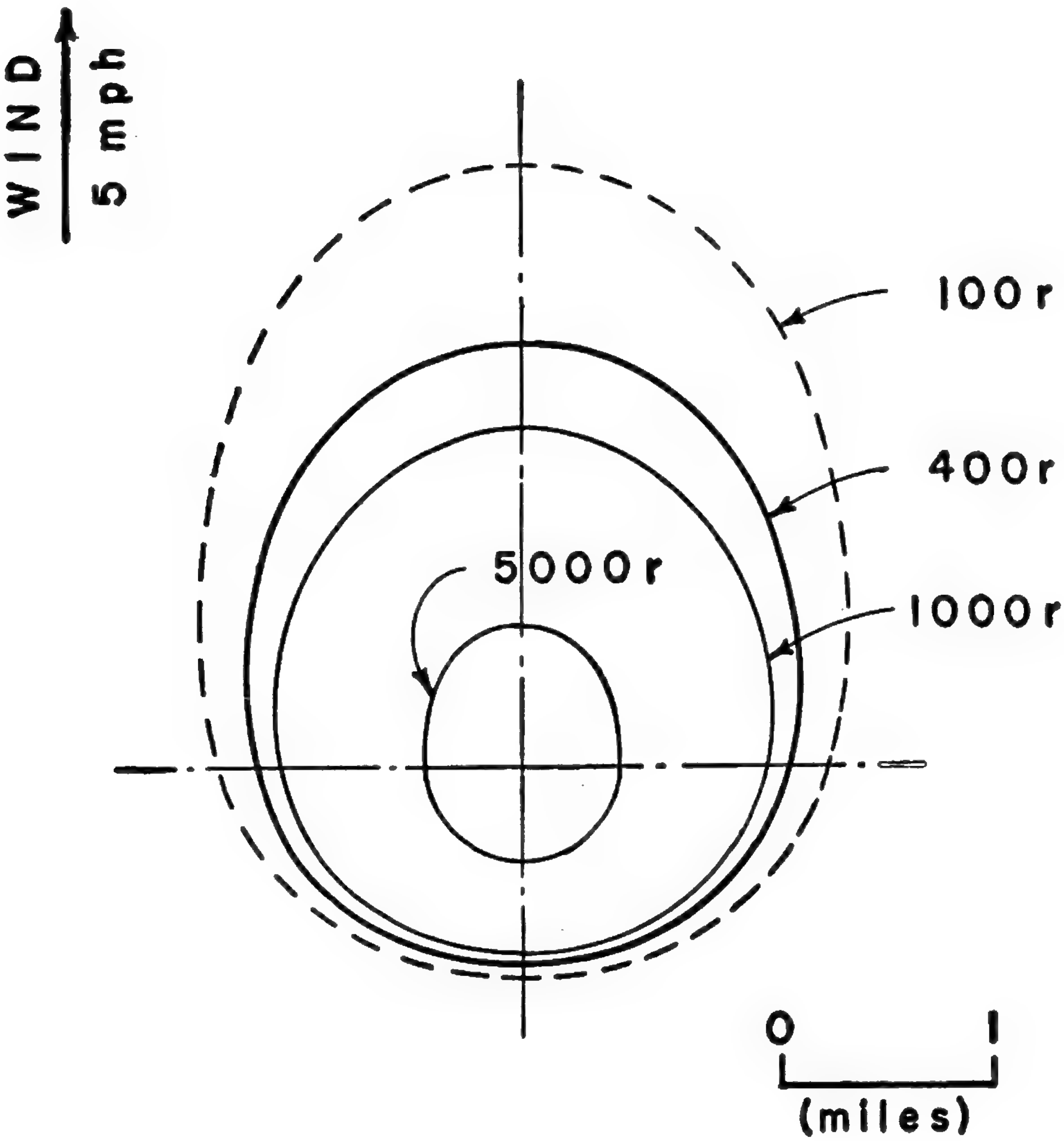


Figure 8.91b. Contours for various integrated radiation dosages due to contamination from underwater burst.

8.92 The integrated dosage contours resulting from contamination due to rain from both the base surge and the fall-out from the atomic cloud, are given in Fig. 8.91b, while Fig. 8.91c indicates the contours for total dosage, i. e., the sum of the base surge and contamination dosages. It is probable that the data in Fig. 8.91b, and hence also in Fig. 8.91c, represent an underestimate, because a proportion of the contaminated water falling as rain ran off the decks of

[19] For the effect of wind on the area, etc., of the base surge, see § 4.79.

the ships and back into the lagoon, so that its activity was not included in the measured dosage.

8.93 It may be mentioned that the radioactive mist of the base surge is most hazardous within the first few minutes of its formation.

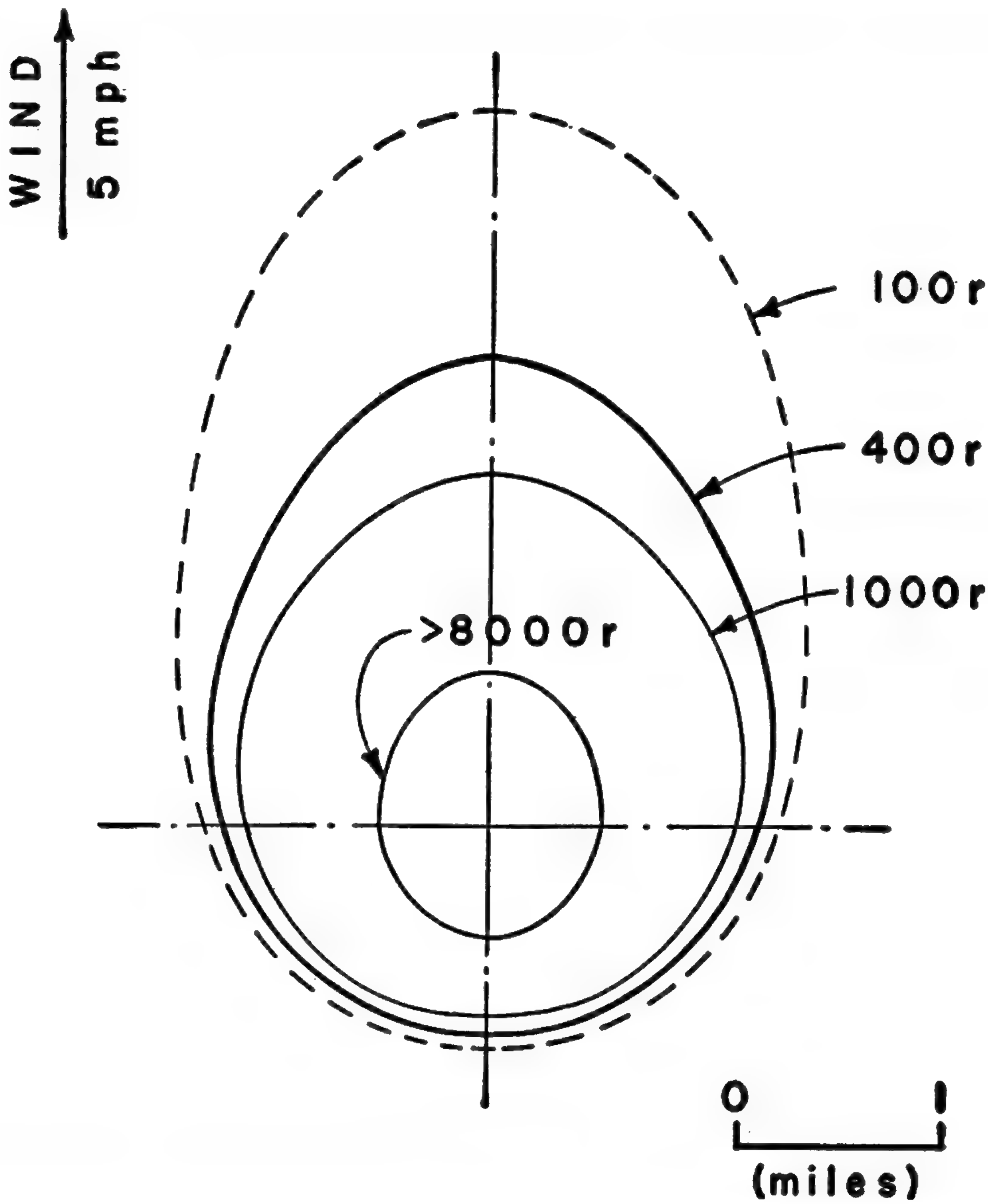


Figure 8.91c. Contours for total dosage due to base surge and contamination from underwater burst.

Its activity decreases rapidly in the course of a short time due to the operation of three factors, namely, dilution by increase of volume as a result of mixing with air, raining out of the active material as the droplets increase in size, and natural radioactive decay. Calculations which probably give a correct order of magnitude, at least, indicate that the dosage rate within the base surge decreases by a factor of about 400 in the interval between 1 and 4 minutes after the

underwater burst. This rapid decrease indicates the advantage of protection from the base surge mist during the 3 or 4 minutes immediately following an atomic explosion. At Bikini, contamination of the interior of the ships, due to the base surge, was minimized by closing down the hatches and stopping the ventilating systems. Attention to this point, especially in the early stages, would obviously prove well worth while.

Radioactivity of Water

8.94 It was recorded earlier that in an underwater burst of an atomic bomb most of the radioactivity of the fission products ultimately appears in the water. Because of the large volume in which these substances are dispersed, the activity in the water is not as high as might be feared, except close to the explosion center and within a short time of the burst. As a result of diffusion of the active material, mixing with water from outside the contaminated area, and natural decay of the radioactivity, the dosage decreases with fair rapidity in a short time. In Table 8.94 are given the area and mean

Table 8.94

DIMENSIONS AND MAXIMUM DOSAGE RATE OF CONTAMINATED WATER IN BIKINI LAGOON

Time after explosion (hours)	*Contaminated area (square miles)*	*Mean diameter (miles)*	*Maximum dosage rate (r per day)*
4	16. 6	4. 6	75
38	18. 4	4. 8	10
62	48. 6	7. 9	5
86	61. 8	8. 9	1
100	70. 6	9. 5	. 6
130	107	11. 7	. 2
200	160	14. 3	. 01

diameter of the contaminated portion of the lagoon after the Bikini "Baker" test, together with maximum observed dosage rates at various times after the burst.

8.95. It is evident that, although a ship would not wish to remain in the contaminated area for any length of time soon after the explosion, passage across the water would not be a great hazard. It is to be understood, of course, that condensers and evaporators would have to be closed down while the ship is in contaminated waters. Further, because of the decrease in activity with time, it seems unlikely that an underwater burst of an atomic bomb would prevent operation of a harbor for any length of time, at least as far as contamination of the water is concerned. However, it should be borne in mind that the

results in Table 8.94, although probably fairly representative, would be affected by the geophysical conditions of the harbor.

8.96 Another factor which contributed to the loss in activity of the water at Bikini was settling of the fission products to the bottom of the lagoon. To judge from samples of bottom material collected 7 and 16 days after the explosion, a considerable proportion of the active material must have been ultimately removed in this manner. The results indicate that the major deposition had occurred within a week and that it covered an area of over 60 square miles. On the assumption that the fission products had penetrated to a depth of 1 foot, it can be estimated that the total mass of the bottom material, in which the radioactivity was distributed, was about 1.4×10^8 tons. Consequently, even though the total initial activity of the fission products was high, about 2×10^6 curies measured a week after the explosion, its wide distribution at the bottom of the lagoon would mean that it did not represent a great hazard to marine life. Observations made several months after the explosion indicated, too, that there was no tendency for the contaminated material to spread.

8.97 It is of interest in this connection to calculate the amount of radiation due to the radioactive isotope of potassium, mass number 40, in sea water. This isotope is present to the extent of 0.012 percent in all forms of potassium, regardless of its source. It emits a beta particle, with a maximum energy of 1.3 Mev, and a gamma photon of 1.5-Mev energy. Because of its long half life, about 1.5×10^9 years, the activity is normally of little significance, although it makes an appreciable contribution to the total background radioactivity of the body (§ 8.49). Since sea water contains 0.4 gram of potassium per liter, the total weight of radiopotassium 40 in the Bikini lagoon is estimated to be 1.4×10^9 grams or 2.1×10^{31} atoms. From the known half life it can be calculated that there will be a total of about 4×10^{14} disintegrations per second, which is equivalent to 10^4 curies of activity due to the potassium 40 alone. In other words, the normal background activity of Bikini lagoon, before the atomic bomb explosion, was at least 10^4 curies. This is not very different from the fission product activity collected at the bottom about 18 months after the detonation.

8.98. There is a possibility that after an underwater burst of an atomic bomb, the radioactivity might be spread over a large area due to the action of marine life. It is well known that land plants absorb and so concentrate mineral elements from the soil and that these are further concentrated in animals feeding on the plants. Similar circumstances arise in water environments; the simple plants, i. e.,

phytoplankton and algae, absorb the nutritive salts from the water, and they are then accumulated in the larger aquatic forms, e. g., fish, which directly or indirectly consume the simple plants.

8.99 In water containing radioactive materials, the latter are concentrated by the fish in the same manner and for the same length of time as are the stable forms of the corresponding elements. If the fish die, the radioactive isotopes are not lost, but they return to the water, as do the stable isotopes, to take part once again in the life cycle. Because of the landlocked nature of the Bikini lagoon, there is evidently little or no outward migration of the larger aquatic organisms so that, as mentioned above, there is no appreciable tendency for the radioactivity to spread. However, due to the behavior of the anadromous migratory fishes, e. g., salmon, shad, etc., which feed in the sea and then migrate upstream to die, or of birds that concentrate the minerals of the sea in guano, there might be some distribution of radioactivity in other cases following an underwater atomic explosion. The extent of such dispersion and its effects would depend greatly on circumstances and appears difficult to estimate.

Radioactive Contamination of Land Areas

8.100 The underwater burst at Bikini took place far enough from shore to prevent any appreciable contamination of land areas. Some radioactive rain fell at large distances from the explosion center (§ 2.36), but the activity was not serious. The possibility must be considered, however, of an underwater atomic explosion so near to the shore that significant amounts of the fall-out and the base surge will reach the adjacent land areas, and possibly affect dock facilities, warehouses, etc. As indicated earlier, because some of the radioactively contaminated water ran off the ships at Bikini, the values in Figs. 8.91b and 8.91c may represent an underestimate if applied to the shore. However, there may be compensating factors in the deposition of active material on the roofs or protruding portions of buildings, and also because of the shielding effects of various structures.

8.101 A rough attempt to assess the contamination, in terms of radiation dosage rates, of adjacent land areas from the underwater burst of a nominal atomic bomb, at 1 hour after the explosion is made in Fig. 8.101. The results are based on the assumption that the activity is due to fission products with a mean gamma-ray energy of 0.7 Mev (§ 8.11). Four contour lines are shown, representing radiation dosage rates of 400, 50, 10, and almost zero roentgens per hour, respectively. In the region outside the last contour line, the danger

due to radioactivity may, in general, although probably not always, be ignored. It should be noted that the results are based on the assump-

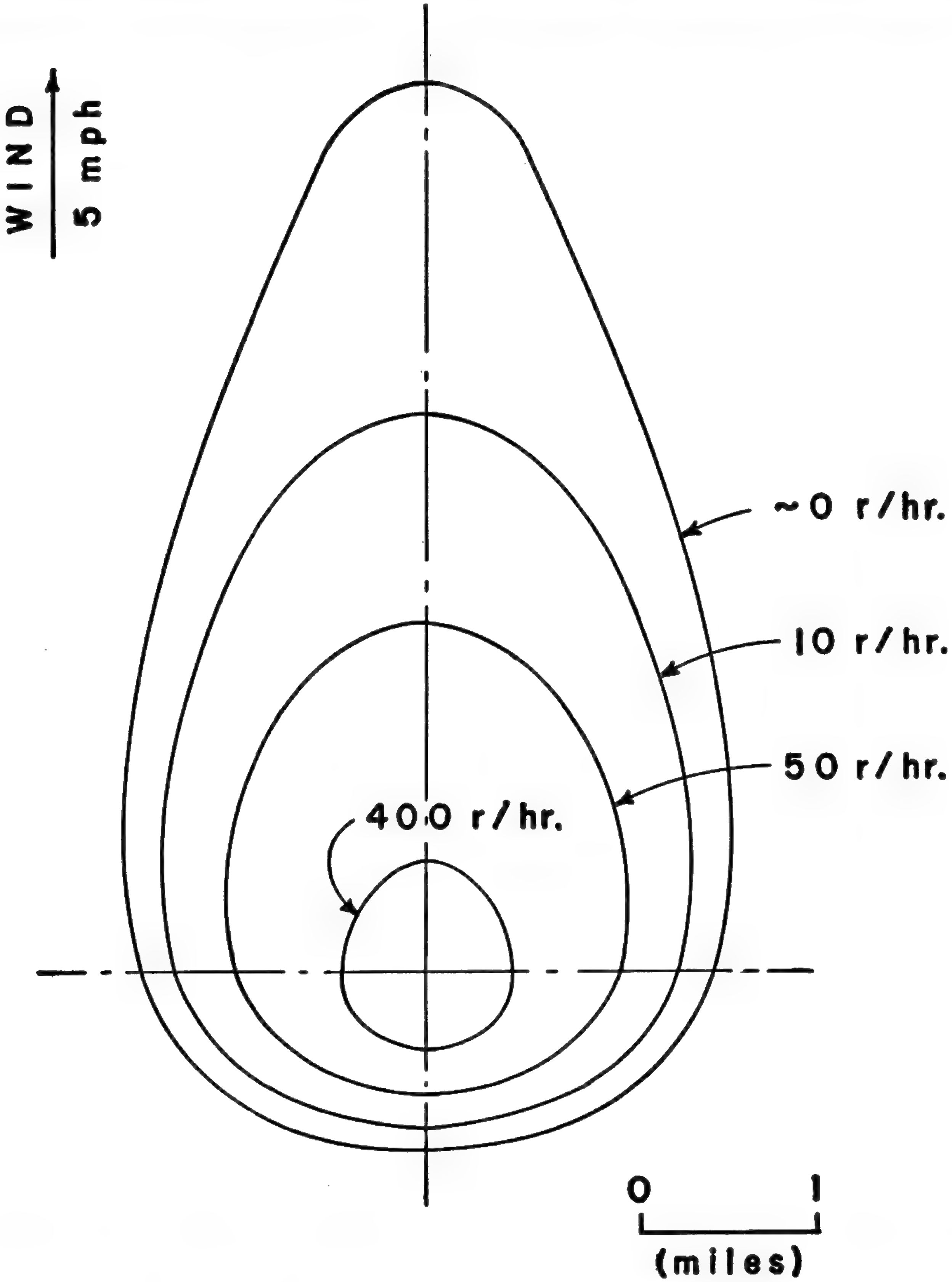


Figure 8.101. Radiation dosage rate contours at 1 hour after explosion due to fission products from underwater burst.

tion that a 5-mile-per-hour wind is blowing, as was the case at Bikini. A difference in the wind velocity or a change in the direction or velocity within a short time after the explosion would, of course, alter the picture appreciably.

12.59 If a person is in the open when the sudden illumination is apparent, then the best plan is instantaneously to drop to the ground, while curling up so as to shade the bare arms and hands, neck, and face with the clothed body. Although this will not protect against gamma rays, it may help in reducing flash burns (§ 6.53). This is important since disabling burns can be suffered well beyond the lethal range for gamma rays (Fig. 12.13). The curled-up position should be held for at least 10 seconds; the immediate danger is then over, and it is permissible to stand up and look around to see what action appears advisable.

12.60 If in the street, and some sort of protection, such as a doorway, a corner or a tree is within a step or two, then shelter may be taken there with the back to the light, and in a crouched position to provide maximum protection, as described above. No attempt should be made to reach a shelter if it is several steps off; the best plan then is to crouch on the ground, as if completely in the open. After 10 seconds, at least, a standing position may be resumed, but it is strongly advisable to press the body tightly against the side of a building to avoid breaking glass or falling missiles, as far as possible.

12.61 A person who is inside a building or home when a sudden atomic bomb attack occurs should drop to the floor, with the back to the window, or crawl behind or beneath a table, desk, counter, etc.; this will also provide a shield against splintered glass due to the blast wave. The latter may reach the building some time after the danger from radiation has passed, and so windows should be avoided for about a minute, since the shock wave continues for some time after the explosion. The safest places inside a building are the interior partitions, and it is desirable to keep as close to these as possible.

D. PROTECTION FROM RESIDUAL RADIATIONS

Introduction

12.62 As stated earlier, protection of large numbers of people from the effects of the residual nuclear radiations, that might follow the explosion of an atomic bomb, represents an entirely new problem concerning which there has been no previous experience. After the attacks on Japan the fission products were so widely dispersed as not to be an appreciable danger; at least, there is no evidence that such a hazard existed. In special circumstances, however, for example, an underwater burst close to the shore or an underground or surface burst, or in the event of the use of radiological warfare weapons, pre-

cautions would have to be taken against the residual radiations. In the present section an outline will be given of the general lines of procedure that might be followed for radiological defense; in view of the lack of experience, these may be regarded as tentative and subject to improvement.

12.63 Since the possibility of combating radioactive contamination is bound up with the extent of the associated physical damage, it is desirable to make a rough classification of the possible combinations that might arise. Three general types may be distinguished:

(*a*) *Heavy Physical Damage and Heavy Contamination.*—Such a condition might be due to a combination of an air-burst atomic bomb followed, or accompanied, by the use of a radiological weapon. In view of the wasteful nature of such action, it may be regarded as not too probable, although it cannot be ignored. An underwater burst in a harbor of a large city, close to the shore, might cause both heavy damage and contamination over a limited area. In this event, radiological safety measures might be delayed by the necessity of clearing away debris, establishing communications, etc.

(*b*) *Heavy Physical Damage and Light Contamination.*—This would arise from an atomic explosion of the type experienced at Hiroshima and Nagasaki. The problem of protection against radioactivity would not be serious in this case. It would be necessary for monitoring teams to follow the radioactive cloud downwind in case there were a marked fall-out in any particular area. It is of almost equal importance to know definitely that there is no hazard.

(*c*) *Moderate or Little Physical Damage and Moderate to Heavy Contamination.*—Such circumstances could arise from a radiological warfare attack, from dry or wet fall-out, from base surge on a ship or on shore at some distance from an underwater explosion, or from an ineffective ("fizzle") explosion of an atomic bomb. The radioactive protection would be of the greatest significance, and to meet these conditions the radiological defense system must be especially prepared.

Stages of Disaster

12.64 In considering the practical problems of a radiological hazard it may be supposed that there will be three stages, the duration and

severity of which will depend on circumstances described above. These are as follows:

(*a*) *Complete Disorganization.*—In the event of heavy and widespread physical damage, it may be presumed that roads will be blocked for some distance from the explosion, and that all normal communication systems will be out of commission. Emergency transportation and communication, except perhaps for self-contained radio equipment, will not be immediately in effect.

(*b*) *Emergency Control Stage.*—This phase will begin as soon as margin roads have been cleared, and transportation and communication has been reestablished, at least on an emergency scale, so that information can be transmitted to a control room. In the case of moderate physical disaster (§ 12.63 (*c*)), the emergency control phase would start immediately, and might last a week or more.

(*c*) *Recovery Stage.*—The final phase would be reached when most people were out of immediate danger of injury, and there is time to start more thorough decontamination operations where necessary (Chapter X).

12.65 In the emergency control phase, an important factor in the operation of radiological defense is the rapid gathering of data regarding contamination. The radiations which may be encountered are gamma rays and beta particles from fission products, neutron-induced activity or other radioactive material, and alpha particles from plutonium or uranium. Of these, the gamma radiation can be measured most readily; this is perhaps the greatest immediate hazard because of its considerable penetrating power. Beta particles as such are not a serious menace unless the source enters the system or remains on the skin for some time.

12.66 Monitoring of suspected contaminated areas for gamma radiation should be carried out at the earliest possible moment after an atomic explosion in which such contamination is likely to have been produced. Initially, this might even be done by means of low-flying aircraft; from the gamma radiation dosage measured at a known height above the ground it will be possible to obtain an approximate indication of the area and intensity of contamination (see Fig. 8.35). However, ground monitoring for gamma radiation, with portable instruments, will be necessary at the first opportunity. The monitoring for beta radiation will, in general, be an auxiliary measurement, made in the later stages after the immediate emergency has passed.

12.72 In the recovery stage, the main objective would be to achieve as effective decontamination as possible so as to reduce the general contamination level to that permitted for routine workers with radioactive material, e. g., 0.3 r per week (§ 8.4). Although there is not complete agreement on the subject, because of the lack of adequate knowledge, the information given in Table 12.72 may

TABLE 12.72

PERMISSIBLE CONTAMINATION

Contaminated material	*Fission product*	*Alpha-emitter*
Air	2×10^{-10} microcurie/cc	2.5×10^{-11} microgram/cc.
Water	4×10^{-6} microcurie/cc	2×10^{-5} microgram/cc.

be taken as indicating a few approximate permissible contamination levels for continued exposure. It is assumed that plutonium is the alpha emitter, since this is probably the most dangerous of those likely to be encountered.

12.73 It should be noted that the figures given in the table refer to permissible levels for personnel exposed to radiation every day, as a result of their peacetime occupation.

12.74 With regard to the internal radiation hazard, it is not possible to make any sound estimate of the amount of material which is likely to be ingested in various circumstances. A person working under normal indoor conditions, for example, would absorb much less than one engaged in an occupation in which there was much dust. Children, because of their habits and closeness to the ground, would be expected to ingest more than adults. These factors would greatly complicate a rehabilitation program, and make it almost impossible to attempt to assess universal permissible contamination levels.

MONITORING EQUIPMENT

12.75 All emergency workers, no matter what their duties, who are sent into areas contaminated with beta or gamma radiation, should be provided with, or closely accompanied by, instruments for personnel monitoring (see Chapter IX). During the disorganization phase and for part, at least, of the emergency control phase, these would have to be of the self-reading, pocket dosimeter type. Instruments of various total ranges, in roentgens, are available, and it would be necessary to use the particular range appropriate to the work to be undertaken. Provision must be made for recharging the dosimeters after each period of use, for otherwise they would be valueless.

The Effects of Nuclear Weapons

SAMUEL GLASSTONE
Editor

Prepared by the
UNITED STATES DEPARTMENT OF DEFENSE
Published by the
UNITED STATES ATOMIC ENERGY COMMISSION
June 1957

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price $2.00 (paper bound)

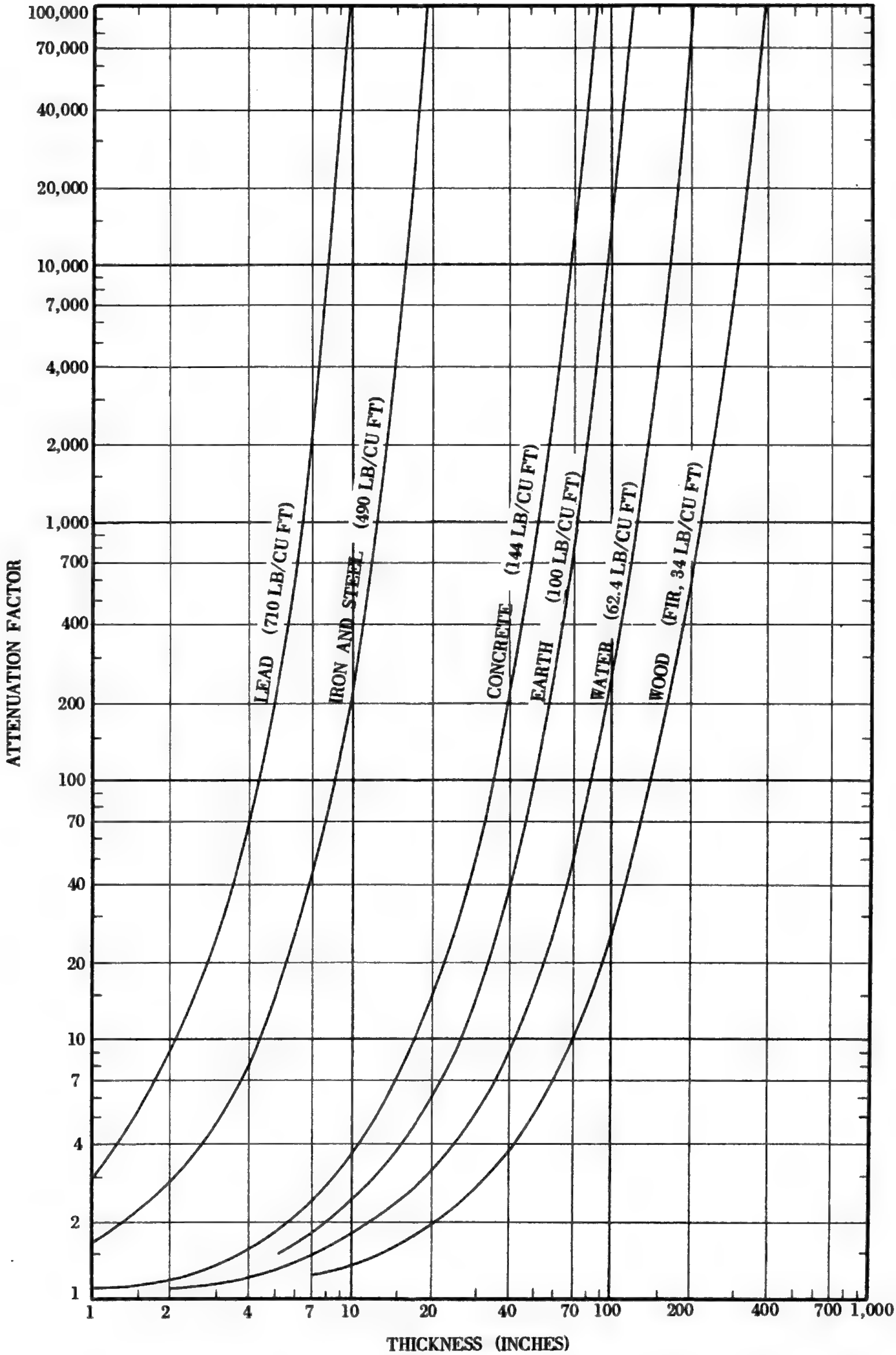
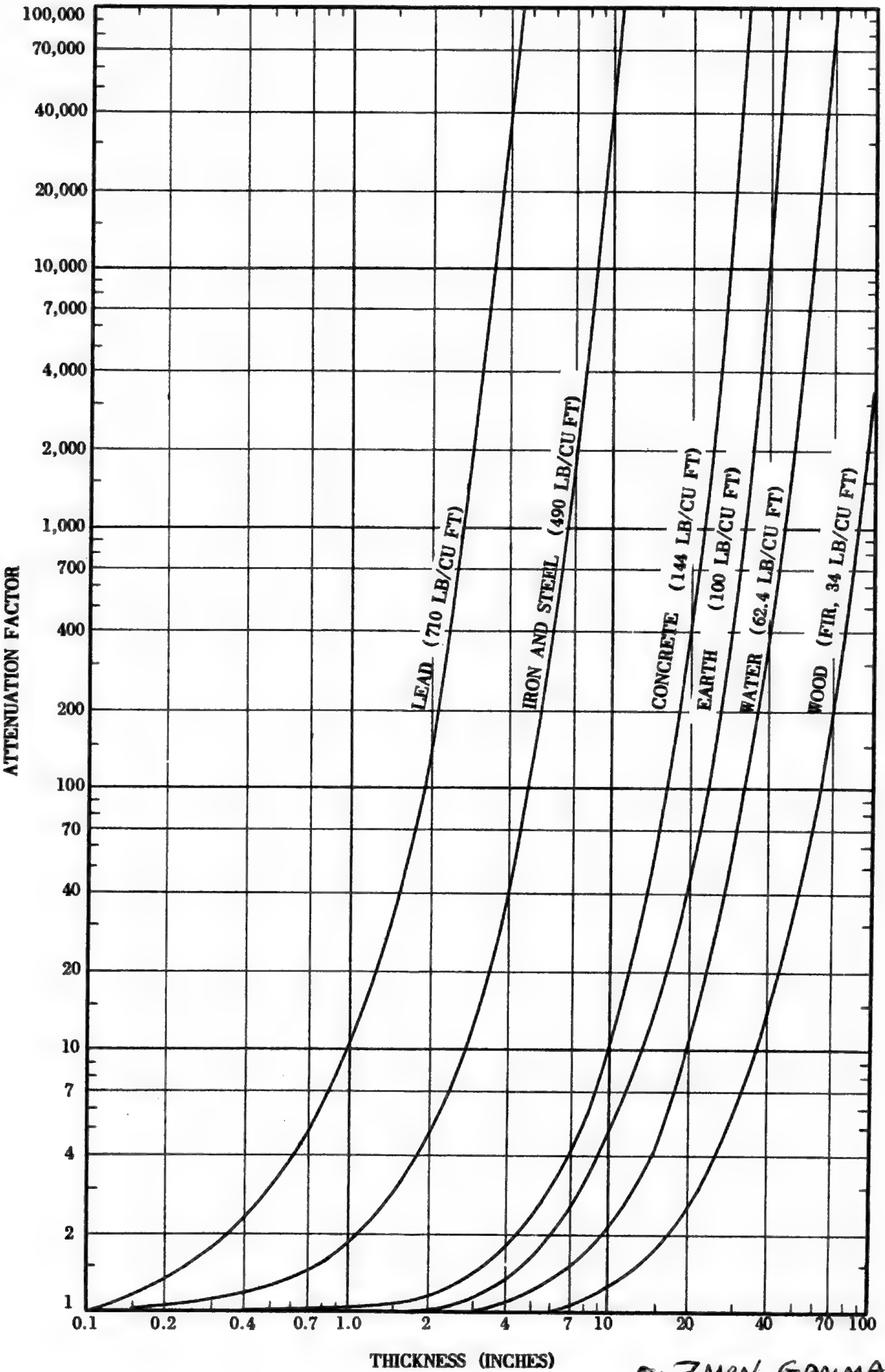


Figure 8.47. Attenuation of initial gamma radiation.



0.7 MeV GAMMAS

Figure 9.36. Attenuation of fission product radiation. (FALLOUT)

CHAPTER XII

PROTECTIVE MEASURES

INTRODUCTION

Types of Protection

12.1 In the preceding chapters of this book the destructive effects of nuclear weapons have been described and discussed. These effects include damage to structures and injury to personnel caused by air blast, ground and water shock, thermal radiations, and initial and residual nuclear radiations. In the present chapter an attempt will be made to state some of the many considerations involved in planning countermeasures against these various effects. The problem of protection is a complex one, since it involves not only the effects themselves, but also economic, social, and psychological considerations, in addition to the methods and efficacy of the systems for providing warning of an impending attack.

12.2 The descriptions of various effects in this book have been given in terms that are reasonably exact. But in planning protection, so many uncertainties are encountered that precise analysis of a particular situation is impossible. Among the more obvious variables are the aiming point for a given target, yield of weapon, height and nature of burst, bombing errors, topography of the target, and weather conditions.

12.3 In general, there are two categories of protection against weapons effects; they may be summed up as "distance" and "shielding." In other words, it is necessary either to get beyond the reach of the effects, or to provide protection against them within their radii of damage. The first principle, that of distance, determines the Civil Defense concept of evacuation of populations from potential target areas.[1] In any discussion of evacuation, this book is of value only as an aid to determining what might constitute a safe distance for evac-

[1] The evacuation problem is treated in the following publications of the Federal Civil Defense Administration: "Procedure for Evacuation Traffic Movement Studies," TM–27–1; "Evacuation of Civil Populations in Civil Defense Emergencies," TB–27–1; "Evacuation Check List," TB–27–2.

Figure 12.37a. Precast, reinforced-concrete blast walls (0.85 mile from ground zero at Nagasaki).

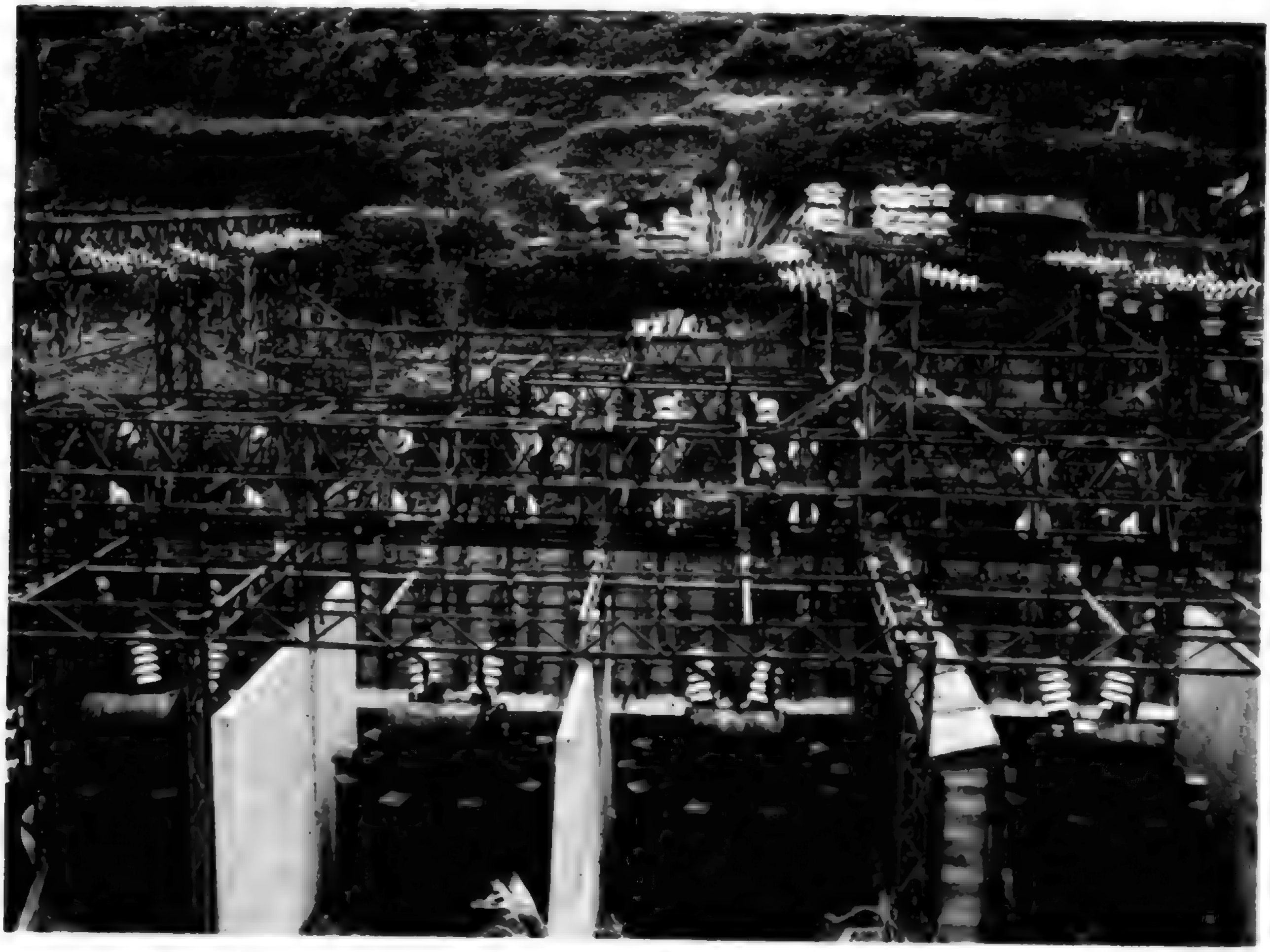


Figure 12.37b. Reinforced-concrete blast walls protecting transformers (1 mile from ground zero at Nagasaki).

Figure 12.37c. Earth-filled, wooden blast walls protecting machinery (0.85 mile from ground zero at Nagasaki).

Protection by Trenches and Earth Revetments

12.38 Although they are not strictly structures, in the sense used above, attention should be called to the significant protection that can be afforded by trenches and earth revetments, especially to drag-sensitive targets. A shallow pit provides little shielding, but pits or trenches that are deeper than the target have been found to be very effective in reducing the magnitude of the drag forces impinging on any part of the target. In these circumstances, the lateral loading is greatly reduced and the damage caused is restricted mainly to that due to the crushing action of the blast wave.

12.39 The only types of shielding against drag forces which have been found to be satisfactory so far are those provided by fairly extensive earth mounds (or revetments) and deep trenches, since these are themselves relatively invulnerable to blast. Such protective trenches are not recommended for use in cities, however, because of the damage that would result from debris falling into them. Although sandbag mounds have proved satisfactory for protection against conventional high explosives and projectiles, they are inadequate against nuclear blast because they may become damaging missiles.

Figure 12.40a. Earth-moving equipment subjected to nuclear blast in open terrain (30 psi overpressure).

Figure 12.40b. Earth-moving equipment subjected to nuclear blast in open terrain (30 psi overpressure).

Figure 12.40c. Earth-moving equipment protected in deep trench at right angles to blast wave motion (30 psi overpressure).

12.40 The destruction caused by a nuclear explosion to two pieces of earth-moving equipment, which are largely drag-sensitive, is shown in Figs. 12.40a and b. Two similar pieces of equipment located in a deep trench, at the same distance from the explosion, are seen in Fig. 12.40c to have been essentially unharmed. It is important to mention that the main direction of the trench was at right angles to the motion of the blast wave. If the wave had been traveling in the same direction as the trench, the equipment would probably have been severely damaged. Consequently, in order to provide protection from drag forces, the orientation of the trench or earth revetment, with respect to the expected direction of the explosion, is of great importance.

Fire Protection

12.41 It was noted in Chapter VII that fires following a nuclear explosion may be started by thermal radiation and by secondary effects, such as overturning stoves and furnaces, rupture of gas pipes, and electrical short circuits. Fire-resistive construction and avoidance of fabrics and other light materials of inflammable character are essential in reducing fire damage. As shown by the tests described in § 7.82, a well-maintained house, with a yard free from inflammable rubbish, was less easily ignited by thermal radiation than a house that has not had adequate care.

12.42 The methods of fire-resistive design and of city planning are well known and the subject need not be treated here. A special requirement is the reduction of the chances of ignition due to thermal radiation by the avoidance of trash piles and other finely divided fuel as well as combustible, especially dark colored, materials that might be exposed at windows or other openings. It has been recommended, in this connection, that all such openings be shielded against thermal radiation from all directions. The simple device of whitewashing windows will greatly reduce the transmission of thermal radiation and so decrease the probability of fires starting in the interior of the building. Other practical possibilities are the use of metal venetian blinds, reflective coatings on the window glass, and nonflammable interior pull curtains.

12.43 To judge from the experience in Japan, where the distortion by heat of exposed structural frames was considerable, it would appear desirable that steel columns and other steel members be protected from fire, especially where the contents of the building are flammable or where the building is located adjacent to flammable structures. Further, narrow firebreaks in Japan were found to be of little value. It is vital, therefore, that such firebreaks as may be provided in city planning or by demolition must be adequate for a major conflagration. A minimum width of 100 feet has been suggested.

12.44 One of the most important lessons learned from the nuclear bomb attacks on Japan is the necessity for the provision of an adequate water supply for the control of fires. In Nagasaki, the water pressure was 30 pounds per square inch at the time of the explosion, but chiefly because of numerous breaks in house service lines it soon dropped to 10 pounds per square inch. On the day following the explosion the water pressure was almost zero. This drop in the pressure contributed greatly to the extensive damage caused by fire. The experience in Hiroshima was quite similar.

SHELTERS FOR PERSONNEL

Introduction

12.45 Ideally, a shelter for personnel might be required to provide protection against air blast, ground shock, thermal radiation, initial nuclear radiation (neutrons and gamma rays), and residual nuclear radiation from fallout (external and internal sources). Such an ideal shelter is, however, virtually impossible to attain, in view of the uncertainties mentioned in § 12.2. Thus, shelter design, like that of

12.60 In the event of a surprise attack, when there is no opportunity to take shelter, immediate action could mean the difference between life and death. The first indication of an unexpected nuclear explosion would be a sudden increase of the general illumination. It would then be imperative to avoid the instinctive tendency to look at the source of light, but rather to do everything possible to cover all exposed parts of the body. A person inside a building should immediately fall prone and crawl behind or beneath a table or desk. This will provide a partial shield against splintered glass and other flying missiles. No attempt should be made to get up until the blast wave has passed, as indicated possibly by the breaking of glass, cracking of plaster, and other signs of destruction. The sound of the explosion also signifies the arrival of the blast wave.

12.61 A person caught in the open by the sudden brightness due to a nuclear explosion, should drop to the ground while curling up to shade the bare arms, hands, neck, and face with the clothed body. Although this action may have little effect against gamma rays and neutrons, it might possibly help in reducing flash burns due to thermal radiation. The degree of protection provided will vary with the energy yield of the explosion. As stated in § 7.53, it is only with high-yield weapons that evasive action against thermal radiation is likely to be feasible. Nevertheless, there is nothing to be lost, and perhaps much to be gained, by taking such action. The curled-up position should be held until the blast wave has passed.

12.62 If shelter of some kind, no matter how minor, e. g., in a doorway, behind a tree, or in a ditch, or trench can be reached within a second, it might be possible to avoid a significant part of the initial nuclear radiation, as well as the thermal radiation. But shielding from nuclear radiation requires a considerable thickness of material and this may not be available in the open. By dropping to the ground, some advantage may be secured from the shielding provided by the terrain and surrounding objects. However, since the nuclear radiation continues to reach the earth from the atomic cloud as it rises, the protection will be only partial. Further, as a result of scattering, the radiations will come from all directions.

PROTECTION FROM FALLOUT

Passive and Active Measures

12.63 Protection against the residual nuclear radiation from fallout presents a number of difficult and involved problems. This is so

Figure 12.92 Water-repellent clothing for use in wet decontamination operations.

12.95 In connection with this aspect of personnel protection, there arises the question of the amount of nuclear radiation exposure that is permissible for those taking part in emergency operations. It is difficult, if not impossible, to supply an exact answer, for a great deal will depend upon the circumstances and the risks that must inevitably be taken.

12.96 In those phases of emergencies in which immediate action is required, it would rarely be possible to predict in advance the radiation dose that might be received as a result of such action. The consequences to the exposed individuals, would, therefore, be equally unpredictable. However, where the hazard could be estimated from available dose rate data, it might be possible to establish an approxi-

424278 O—57——35

mate guide concerning permissible radiation exposures under emergency conditions.[7]

Food and Water

12.97 Foods that are properly covered or wrapped or are stored in closed containers should suffer little or no contamination. This will be true for canned and bottled foods as well as for any articles in impervious, dust-proof wrappings. If the contamination is only on the outside, all that would be necessary for recovery purposes would be the careful removal, e. g., by washing, of any fallout particles that might have settled on the exterior of the container.[8] Even vegetables could be satisfactorily decontaminated by washing. If this were followed by removal of the outer layers, by peeling, the food should be perfectly safe for human consumption. Unprotected food products of an absorbent variety that have become contaminated should be disposed of by burial.

12.98 As for food crops grown in contaminated soil, there is not yet sufficient information available. Some radioactive isotopes may be taken up by the plant, but their nature and quantity will vary from one species to another and also, probably, with the soil characteristics (§ 9.99). All that can be stated at the present time is that plants grown in contaminated soil should be regarded with suspicion until their safety can be confirmed by means of radiological instruments.

12.99 Most sources of public water supplies are located at a considerable distance from urban centers that might be targets of a nuclear attack. Nevertheless, appreciable contamination might result if the watershed were in the range of heavy fallout from a surface burst. Other possibilities are fallout particles dropping into a river or reservoir or the explosion of a nuclear bomb near a reservoir. In most cases it is to be expected that, as a result of the operation of several factors, e. g., dilution by flow, natural decay, and removal ("adsorption") by soil, the water will be fit for consumption, on an emergency basis, at least, except perhaps for a limited time immediately following the nuclear explosion. In any event, where the water from a reservoir is subjected to regular treatment, including coagu-

---

[7] See, for example, "Emergency Exposures to Nuclear Radiation," Federal Civil Defense Administration Technical Bulletin (TB–18–1).

[8] Food could become contaminated even inside containers due to neutron-induced activity, but this is not likely to be important in locations where the packaged foodstuffs have survived the nuclear explosion intact (§ 9.25).

lation, sedimentation, and filtration, it is probable that much of the radioactive material would be removed.

12.100 Because soil has the ability to take up and retain certain elements by the process of "adsorption," underground sources of water will generally be free from contamination. For the same reason, moderately deep wells, even under contaminated ground, can be used as safe sources of drinking water, provided, as is almost invariably the case, there is no direct drainage from the surface into the well.

12.101 In some cities, water is taken directly from a river and merely chlorinated before being supplied for domestic purposes. The water may be unfit for consumption for several days, but, as a result of dilution and natural decay, the degree of contamination will decrease with time. It would be necessary, in cases of this kind, to subject the water to examination for radioactivity and to withhold the supply until it is reasonably safe. Assuming the contamination is due to fission products, the acceptable total beta (or gamma) activities under emergency conditions, for 10 and 30 day periods, respectively, are given in Table 12.101. Thus, if it is anticipated that the water will have to be used regularly for a period of 30 days, the maximum permissible activity is 3×10^{-2} microcuries per cubic centimeter (see § 9.125, *et seq.*). On the other hand, if it appears that the period will be shorter, water of proportionately higher activity may be consumed in an emergency.

TABLE 12.101

ACCEPTABLE EMERGENCY BETA (OR GAMMA) ACTIVITIES IN DRINKING WATER

	Activity	
Consumption period (days)	*Microcuries per cubic centimeter*	*Disintegrations per second per cubic centimeter*
10	9×10^{-2}	3×10^{3}
30	3×10^{-2}	1×10^{3}

12.102 The emergency limits for alpha particle emitters, such as uranium and plutonium, in water are appreciably less than those given in Table 12.101. However, it is expected that only in rare circumstances would these elements represent a contamination hazard in drinking water.

12.103 If the regular water supply is not usually subjected to any treatment other than chlorination, and an alternative source is not available, consideration should be given to the provision of ion-exchange columns (or beds) for emergency use in case of contamination.

Home water softeners might serve the same purpose on a small scale. Incidentally, the water contained in a domestic hot-water heater could serve as an emergency supply, provided it can be removed without admitting contaminated water.

12.104 In hospitals and on ships, sufficient water for emergency purposes could be obtained by distillation. It was found after the nuclear tests at Bikini in 1946, for example, that contaminated sea water when distilled was perfectly safe for drinking purposes; the radioactive material remained behind in the residual scale and brine. It should be emphasized, however, that mere boiling of water contaminated with fallout is of absolutely no value as regards removal of the radioactivity.

Radiation Doses and Times in Contaminated Areas

12.105 For the planning of defensive action, either active or passive, or of survey operations in an area contaminated with fission products, it is necessary either to make some estimate of the permissible time of stay for a prescribed dose or to determine the dose that would be received in a certain time period. The basic equations and the related graphs (Figs. 9.8 and 9.12) were given in Chapter IX, but the same results may be expressed in an alternative form that is more convenient for many purposes.[9]

12.106 If the radiation dose rate from fission products is known at a certain time in a given location, Fig. 12.106 may be used to determine the dose rate at any other time at the same location, assuming there has been no change in the fallout other than natural radioactive decay. The same nomogram can be utilized, alternatively, to determine the time after the explosion at which the dose rate will have attained a specified value. If there has been any change in the situation, either by further contamination or by decontamination, in the period between the two times concerned, the results obtained from Fig. 12.106 will not be valid.

12.107 To determine the total radiation dose received during a specified time of stay in a contaminated area, if the dose rate in that area at any given time is known, use is made of Fig. 12.107, in conjunction with Fig. 12.106. The chart may also be employed to evaluate the time when a particular operation may be commenced in order not to exceed a certain total radiation dose.

---

[9] Devices of the slide-rule type, referred to in the footnote to § 9.11, are very useful for making rapid calculations of the kind described here.

Fireball of the world's first thermonuclear explosion, Eniwetok Proving Grounds, November 1, 1952 (local time).

The Effects of

Nuclear Weapons

SAMUEL GLASSTONE

Editor

Revised Edition
Reprinted February 1964

Prepared by the

UNITED STATES DEPARTMENT OF DEFENSE

Published by the

UNITED STATES ATOMIC ENERGY COMMISSION

April 1962

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C. - Price $3.00 (paper bound)

Foreword

This book is a revision of "The Effects of Nuclear Weapons" which was issued in 1957. It was prepared by the Defense Atomic Support Agency of the Department of Defense in coordination with other cognizant governmental agencies and was published by the U.S. Atomic Energy Commission. Although the complex nature of nuclear weapons effects does not always allow exact evaluation, the conclusions reached herein represent the combined judgment of a number of the most competent scientists working on the problem.

There is a need for widespread public understanding of the best information available on the effects of nuclear weapons. The purpose of this book is to present as accurately as possible, within the limits of national security, a comprehensive summary of this information.

Secretary of Defense

Chairman
Atomic Energy Commission

Figure 7.33a. Thermal effects on wood-frame house 1 second after explosion (about 25 cal/sq cm).

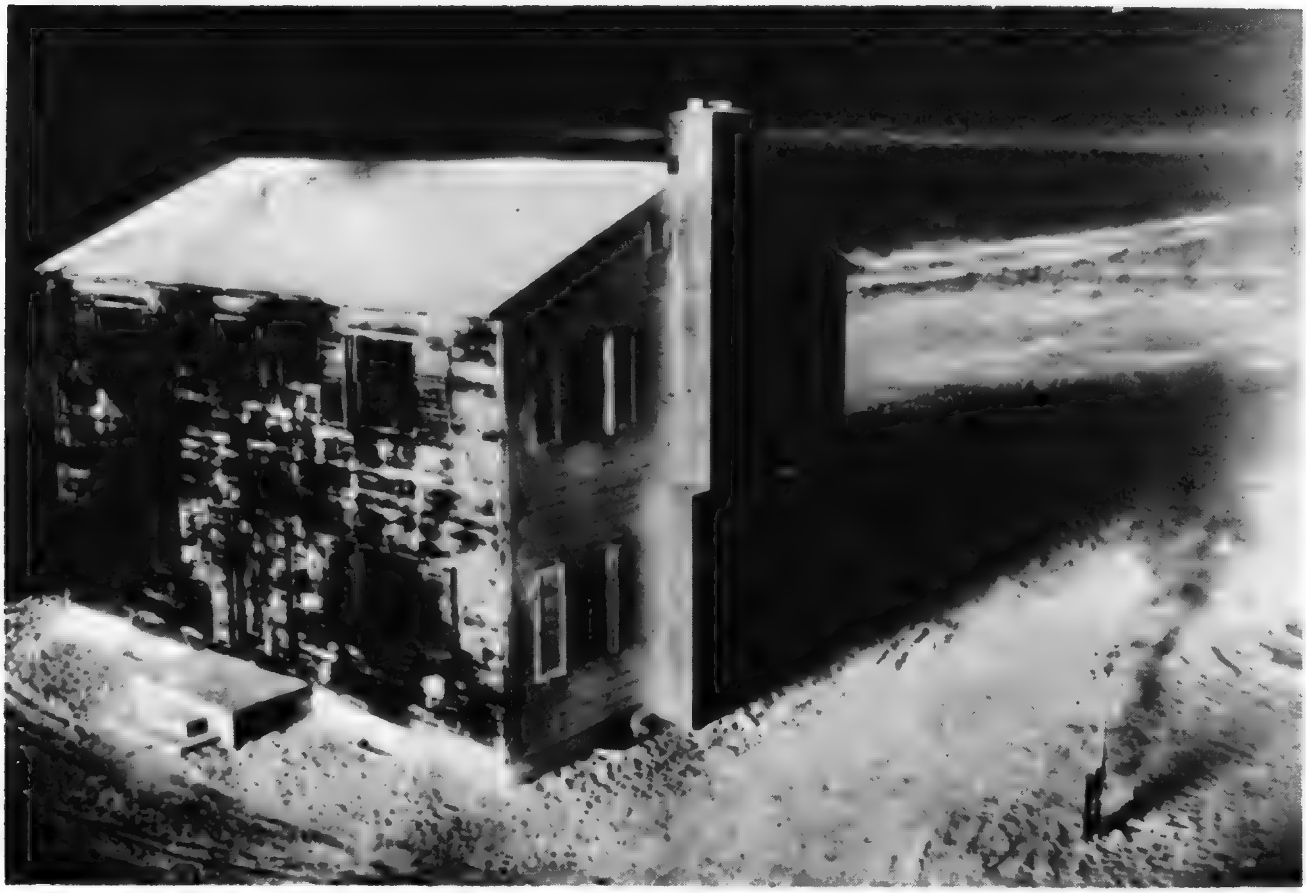


Figure 7.33b. Thermal effects on wood-frame house about ¾ second later.

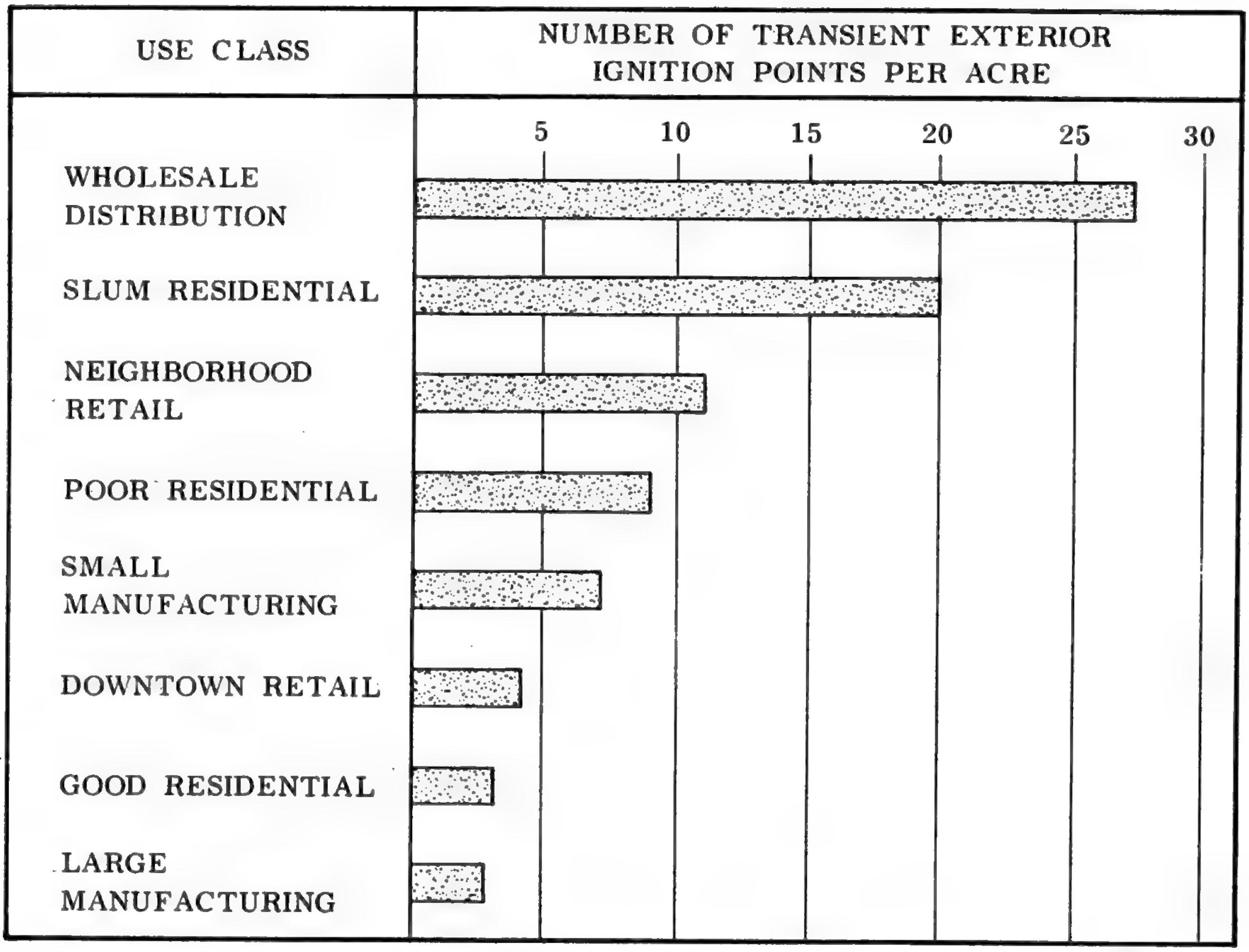


Figure 7.55. Frequency of exterior ignition points for various areas in a city

the formation of a significant fire, capable of spreading, will require appreciable quantities of combustible material close by, and this may not always be available.

7.57 The fact that accumulations of ignitable trash close to a wooden structure represent a real fire hazard was demonstrated at the nuclear tests carried out in Nevada in 1953. In these tests, three miniature wooden houses, each having a yard enclosed with a wooden fence, were exposed to 12 calories per square centimeter of thermal radiation. One house, at the left of Fig. 7.57, had weathered siding showing considerable decay, but the yard was free from trash. The next house also had a clean yard and in addition, the exterior siding was well maintained and painted. In the third house, at the right of the photograph, the siding, which was poorly maintained, was weathered, and the yard was littered with trash.

7.58 The state of the three houses after the explosion is seen in Fig. 7.58. The third house, at the right, soon burst into flame and was burned to the ground. The first house, on the left, did ignite but it did not burst into flame for 15 minutes. The well maintained house in the center with the clean yard suffered scorching only. It is of interest to recall that the wood of a newly erected white-painted

Figure 7.57. Wooden test houses before exposure to a nuclear explosion, Nevada Test Site.

Figure 7.58. Wooden test houses after exposure to a nuclear explosion.

house exposed to about 25 calories per square centimeter was badly charred but did not ignite (see Fig. 7.33b).

7.59 The value of fire-resistive furnishing in decreasing the number of ignition points was also demonstrated in the tests. Two identical, sturdily constructed houses, each having a window 4 feet by 6 feet facing the point of burst, were erected where the thermal radiation exposure was 17 calories per square centimeter. One of the houses contained rayon drapery, cotton rugs, and clothing, and, as was expected, it burst into flame immediately after the explosion and burned completely. In the other house, the draperies were of vinyl plastic, and rugs and clothing were made of wool. Although much ignition occurred, the recovery party, entering an hour after the explosion, was able to extinguish the fires.

7.60 There is another point in connection with the initiation of fires by thermal radiation that needs consideration. This is the possibility that the flame resulting from the ignition of a combustible material may be subsequently extinguished by the blast wind. It was thought that there was evidence for such an effect from an observation made in Japan (§ 7.67), but this may have been an exceptional case. The matter has been studied, both in connection with the effects in Japan and at various nuclear tests, and the general conclusion is that the blast wind has no significant effect in extinguishing fires (§ 7.68).

Spread of Fires

7.61 The spread of fires in a city, including the development of a "fire storm" to which reference is made in § 7.75, depends upon a variety of conditions, e.g., weather, terrain, and closeness and combustibility of the buildings. Information concerning the growth and spread of fires from a large number of ignition points, such as might follow a nuclear explosion, and their coalescence into large fires (or conflagrations) is limited to the experience of World War II incendiary raids and the two atomic bomb attacks. There is consequently some uncertainty concerning the validity of extrapolating from these limited experiences to the behavior to be expected in other cities. It appears, however, that if other circumstances are more-or-less the same, an important criterion of the probability of fire spread is the distance between buildings. It is evident, from general considerations, that the lower the building density or "built-upness" of an area, the less will be the probability that fire will spread from one structure to another. Furthermore, the larger the spaces between buildings the greater the chances that the fire can be extinguished.

7.62 The curve in Fig. 7.62 gives a rough idea of how the probability of fire spread, expressed as a percentage, depends upon the average distance between buildings in a city. The results will be dependent, to some extent, upon the types of structures involved, e.g., whether they are fire-resistive or not, as well as upon the damage caused by the blast wave. It should be noted that Fig. 7.62 applies to fire spread accompanying a nuclear explosion, when a large number of small fires are started directly by thermal radiation and indirectly in other ways.

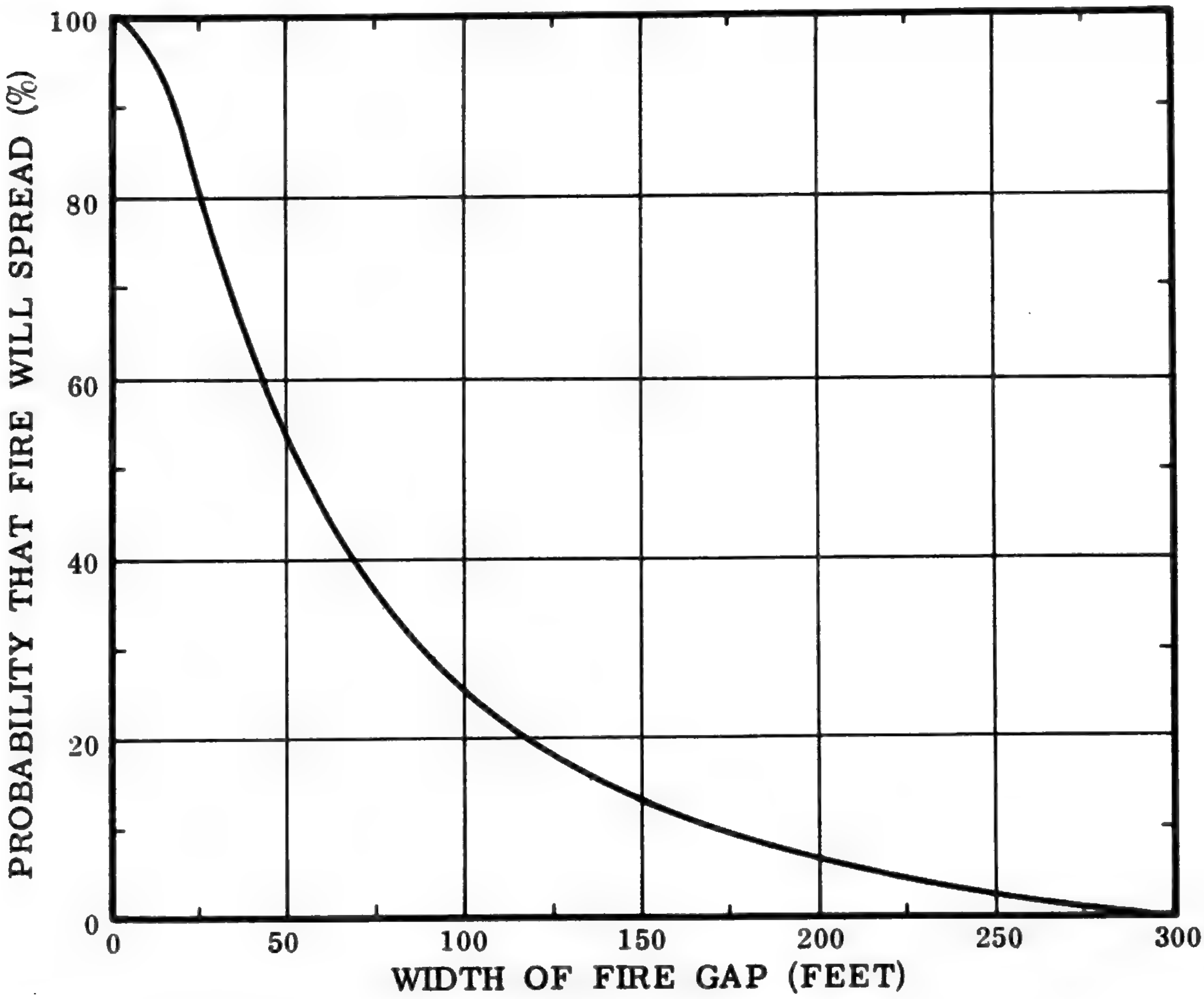


Figure 7.62. Width of gap and probability of fire spread.

7.63 Another aspect of fire spread is the development of mass fires in a forest following primary ignition of dried leaves, grass, and rotten wood by the thermal radiation. Some of the factors which will influence the growth of such fires are the moisture content of the trees, topography, and meteorological conditions. Low atmospheric humidity, strong winds, and steep terrain favor the development of forest fires. In general, a deciduous forest, particularly when in leaf, may be expected to burn less rapidly and with less intensity than a forest of coniferous trees. Green leaves and the trunks of trees would act as shields against thermal radiation, so that the number of points at which ignition occurs in a forest may well be less than would appear at first sight.

7.76 It should be noted that the fire storm is by no means a special characteristic of nuclear weapons. Similar fire storms have been reported as accompanying large forest fires in the United States, and especially after incendiary bomb attacks in both Germany and Japan during World War II. The high winds are produced largely by the updraft of the heated air over an extensive burning area. They are thus the equivalent, on a very large scale, of the draft of a chimney under which a fire is burning. Because of limited experience, the conditions for the development of fire storms in cities are not well known. It appears, however, that some, although not necessarily all, of the essential requirements are the following: (1) thousands of nearly simultaneous ignitions over an area of at least a square mile, (2) heavy building density, e.g., more than 20 percent of the area is covered by buildings, and (3) little or no ground wind. Based on these criteria, only certain sections—usually the older and slum areas—of a very few cities in the United States would be susceptible to fire storm development.

7.77 It should be mentioned that no definite fire storm occurred at Nagasaki, although the velocity of the southwest wind, blowing between the hills, increased to 35 miles an hour when the conflagration had become well established, perhaps about 2 hours after the explosion. This wind tended to carry the fire up the valley in a direction where there was nothing to burn. Some 7 hours later, the wind had shifted to the east and its velocity had dropped to 10 to 15 miles per hour. These winds undoubtedly restricted the spread of fire in the respective directions from which they were blowing. The small number of dwellings exposed in the long narrow valley running through Nagasaki probably did not furnish sufficient fuel for the development of a fire storm as compared to the many buildings on the flat terrain at Hiroshima.

TECHNICAL ASPECTS OF THERMAL RADIATION [5]

Distribution and Absorption of Energy From the Fireball

7.78 Spectroscopic studies made in the course of weapons tests have shown that the fireball does not behave exactly like a black body, i.e., as a perfect radiator. Generally, the proportion of radiations of longer wave length (greater than 5,500 A) [6] corresponds to higher black body temperatures than does the shorter wave emission. The assumption of black body behavior for the fireball, however, serves as a reasonable approximation in interpreting the thermal

[5] The remaining sections of this chapter may be omitted without loss of continuity.

[6] The symbol "A" represents the "angstrom", i.e., 10^{-8} cm, the unit in which radiation wave lengths are commonly expressed.

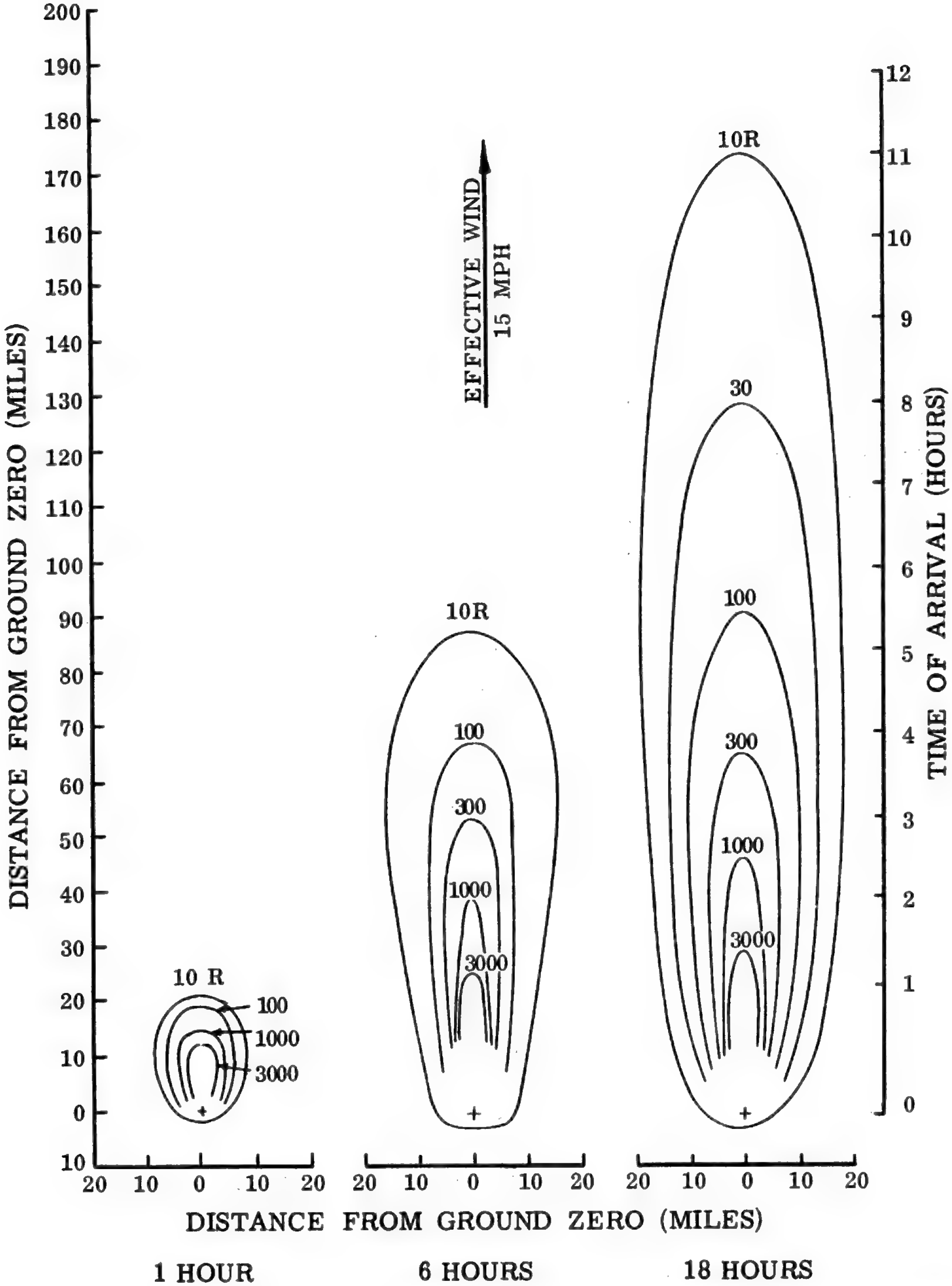


Figure 9.67b. Total-dose contours from early fallout at 1, 6, and 18 hours after surface burst with 1-megaton fission yield (15 mph effective wind speed).

is then due to the natural decay of the fission products. Turning to Fig. 9.67b, it is seen that the total radiation dose received at the given location by 1 hour after the explosion is small, because the fallout has only just started to arrive. By 6 hours, the total dose has

zero at which there was 50-percent survival (for at least 20 days) among the occupants of a number of buildings in Hiroshima. School personnel who were indoors had a much higher survival probability than those who were outdoors at the times of the explosions.

TABLE 11.17

AVERAGE DISTANCES FOR 50-PERCENT SURVIVAL AFTER 20 DAYS IN HIROSHIMA

Conditions	*Approximate distance (miles)*
Overall	0. 8
Concrete buildings	0. 12
School personnel:	
Indoors	0. 45
Outdoors	1. 3

CAUSES OF INJURIES AMONG SURVIVORS

11.18 From surveys made of a large number of Japanese, a fairly good idea has been obtained of the distribution of the three types of injuries among those who became casualties but survived the nuclear attacks. The results are quoted in Table 11.18. It will be observed that the totals add up to more than 100 percent, since many individuals suffered multiple injuries.

TABLE 11.18

DISTRIBUTION OF TYPES OF INJURY AMONG SURVIVORS

Injury	*Percent of survivors*
Blast (mechanical)	70
Burns (flash and flame)	65
Nuclear radiation (initial)	30

11.19 Among survivors the proportion of indirect blast (mechanical) injuries due to flying missiles and movement of other debris was smallest outdoors and largest in certain types of industrial buildings. Patients were treated for lacerations received out to 10,500 feet (2 miles) from ground zero in Hiroshima and out to 12,500 feet (2.2 miles) in Nagasaki. These distances correspond roughly to those at which moderate damage occurred to wood-frame houses, including the shattering of window glass.

11.20 An interesting observation made among the Japanese survivors was the relatively low incidence of serious mechanical injuries.

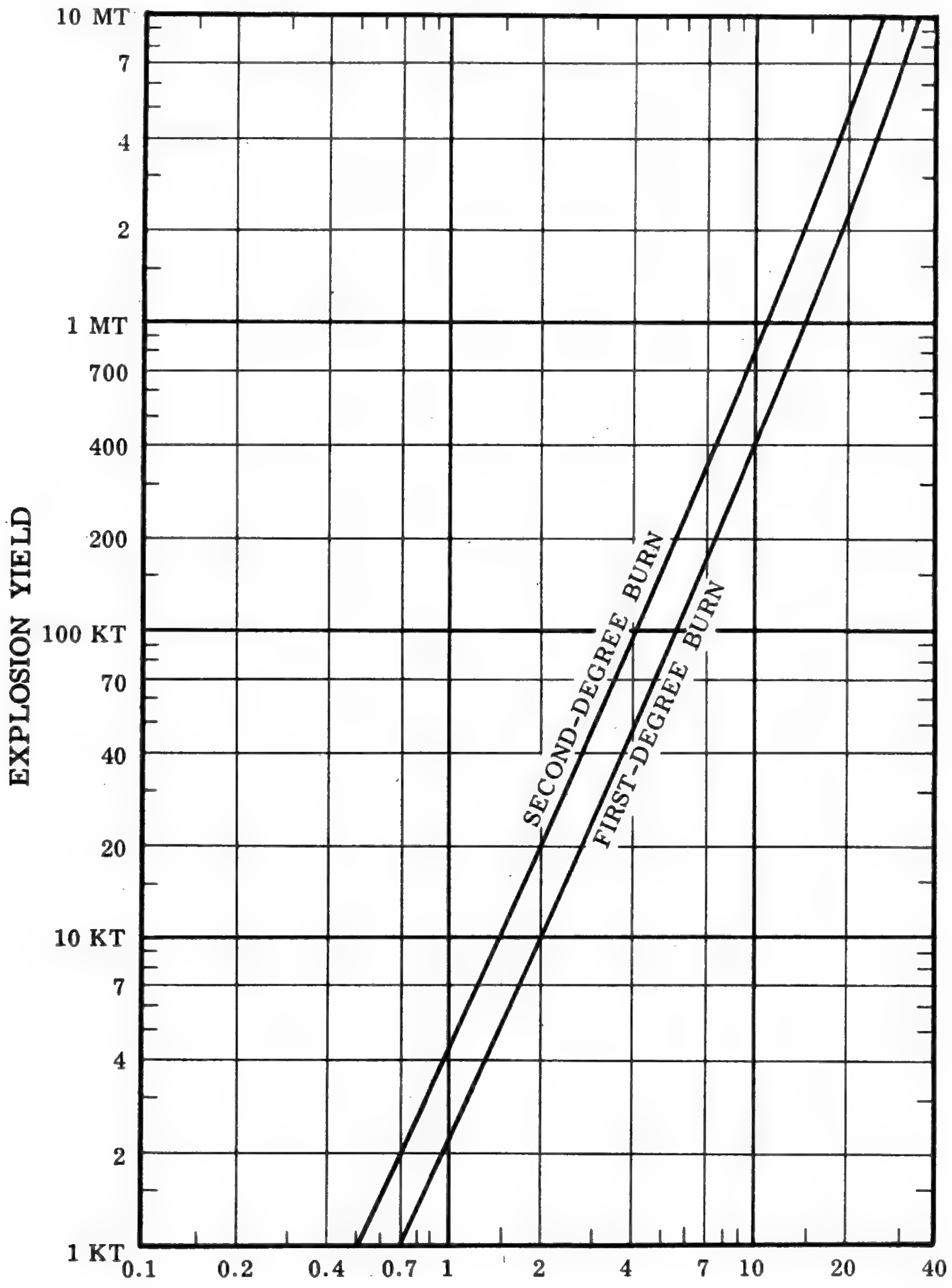


Figure 11.63. Ranges for first- and second-degree burns as a function of the total energy yield.

11.67 Investigators have reported that in no case, among 1,400 examined, was the thermal radiation exposure of the eyes apparently sufficient to produce permanent opacity of the cornea. This observation is not surprising since the cornea is transparent to the major portion of the thermal energy which is received in the visible and longer

wavelength (infrared) parts of the spectrum. In approximately one-quarter of the cases studied there had been facial burns and often singeing of the eyebrows and eyelashes. Nevertheless, some 3 years later the corneas were found to be normal. ← NO EYES BURNED OUT.

11.68 Several reasons have been suggested for the scarcity of severe eye injuries in Japan. For example, the detonations occurred in the morning in broad daylight when the eye pupil would be expected to be small. Another possible explanation is that the recessed position of the eyes and, in particular, the overhanging upper lids served to decrease the direct exposure to thermal radiation. Furthermore, on the basis of probability, it is likely that only a small proportion of individuals would be facing the explosions in such a way that the fireball would actually be in their field of vision.

11.69 The effects of thermal radiation on the eyes fall into two main categories: (1) permanent (chorioretinal burns) and (2) temporary (flash blindness). Concentration of sufficient direct thermal energy, due to the focusing action of the eye lens, can cause the permanent damage. The focusing occurs, however, only if the fireball is in the individual's field of view. When this happens, chorioretinal burns may be experienced at distances from the explosion which exceed those where the thermal radiation produces skin burns. As a result of accidental exposures at nuclear weapons tests, a few burns of this type have been received at distances up to 10 miles from explosions of approximately 20-kilotons energy yield.

11.70 Experiments have been made with rabbits in an attempt to estimate the susceptibility of the human eye to thermal radiation. Although the rabbit eye is smaller, it is similar to the human eye in many respects including pupillary opening. However, under the same exposure conditions, the rabbit retina receives a larger amount of radiant energy per unit area because the rabbit eye, being smaller and having a shorter focal length, produces a smaller image. Estimates of the limiting distances are given in Table 11.70 for chorioretinal burns associated with a 20-kiloton low air burst, based on tests with rabbits and the assumption that, in humans, an exposure of 0.1 calorie per square centimeter for a period of about 0.15 second would produce a minimal eye burn. It should be noted, however, that research suggests this assumption may not be entirely correct. The distances are given for various degrees of atmospheric visibility, as defined in § 7.12, and for different pupil diameters. The importance of the air visibility and the brightness to which the eye is adapted are apparent.

TABLE 11.70

ESTIMATED LIMITING DISTANCES FOR CHORIORETINAL BURNS IN HUMANS FOR A 20-KILOTON LOW AIR BURST

	Pupil Opening Diameter		
	2 mm (Bright sunlight adapted	*4 mm (Cloudy day)*	*8 mm (Completely dark adapted)*
Visibility (miles)	*Distance (miles)*		
25	23	31	40
12	11	16	20
6	6	8	10
2	2	3	4

11.71 The size of the eye lesion produced is uncertain since it depends on the distance from the explosion and severity of the damage. The lesions contain areas of different types and degrees of damage; their relations to yield depend on a variety of factors and cannot be established with the information available at present. In all instances, however, there will be some temporary loss of visual acuity, at least, but the ultimate effect will depend upon the severity of the exposure and, to a greater extent, upon its location. If a chorioretinal burn is mild, or on the periphery of the visual field, the acuity may hardly be affected, but in more serious or centrally located cases there may be considerable loss of vision.

11.72 In a high-altitude detonation, the thermal radiation will generally traverse less of the atmosphere than for an air burst at the same slant range. Consequently, the atmospheric attenuation will be less in the former case in the absence of clouds, and chorioretinal burns may be expected at greater distances from the point of burst for similar energy yields. In order to obtain data concerning the possibility of eye injury, rabbits were exposed to the radiation from the TEAK shot of a megaton-range weapon at an altitude of 252,000 feet (§§ 2.53, 2.123 *et seq.*). Under nighttime conditions, chorioretinal burns occurred at slant distances up to about 345 miles; however, no measurements were made at greater distances and so this cannot be considered as a threshold range for eye damage.

11.73 Although extrapolation of the rabbit data to man is uncertain for high-altitude shots, it is felt that there would be some danger to human beings at distances greater than 200 miles under similar circumstances, and possibly as far as the eye can see at high altitude. It may be concluded from the Japanese situations that the number of individuals who will be looking directly at the fireball in the event of an unexpected air burst will not be large. High-altitude detonations

will be visible over greater distances and so it is probable that more people would actually observe an explosion of this type.

11.74 The size of the fireball image on the retina decreases with increasing slant range from the burst point and hence the radiant energy is received on a smaller area of the retina. The decrease in area largely compensates for the decrease in thermal energy, which varies inversely as the square of the distance from the explosion. In these circumstances, therefore, the thermal energy received per unit area of the retina decreases only as the atmospheric transmittance decreases with increasing distance (§ 7.104). However, because of chromatic aberration, the image on the retina does not become much less than about 10 microns (0.001 cm) in diameter. Consequently, beyond a certain distance from the explosion, the image of the fireball does not decrease further. The radiant exposure then decreases rapidly with increasing distance since it is dependent on both the inverse square of the distance and the atmospheric transmittance.

11.75 Temporary "flash blindness" or "dazzle" can occur in persons who are too far from the explosion to suffer chorioretinal injury or who do not view the fireball directly. Flash blindness results when more thermal energy is received on the retina than is necessary for image perception, but less than is required for burn. The effect is a localized bleaching of the visual elements, with image persistence, after-image formation, halo, etc. From a few seconds to several days may be required for the eye to recover its functions. Dazzle is essentially the same as flash blindness although some authorities reserve the term dazzle for the effect of scattered light reaching the eye in which recovery is much more rapid than with "line of sight" flash blindness. Flash blindness occurs at greater ranges at night, when the eye is dark adapted, than in daylight; however, the range of these effects is highly dependent on atmospheric conditions prevailing at the time of detonation.

11.76 Much of the thermal radiation responsible for chorioretinal burns and flash blindness would arrive so soon after the explosion of a weapon in the kiloton energy range that reflex actions, such as blinking and contraction of the eye pupil, can give only limited protection. The same holds true for high-altitude, kiloton and megaton yield detonations, in which most of the thermal energy is emitted in very short times (§ 7.96). In certain situations with air bursts of high yield, however, the thermal pulse is long enough to permit some protection by the blink reflex.

11.149 Valuable information concerning the development and healing of beta burns has been obtained from observations of the Marshall Islanders who were exposed to fallout in March 1954. Within about 5 hours of the burst, radioactive material commenced to fall on some of the islands. Although the fallout was observed as a white powder, consisting largely of particles of lime (calcium oxide) resulting from the decomposition of coral (calcium carbonate) by heat, the island inhabitants did not realize its significance. Because the weather was hot and damp, the Marshallese remained outdoors; their bodies were moist and they wore relatively little clothing. As a result, appreciable amounts of fission products fell upon the hair and skin and remained there for a considerable time. Moreover, since the islanders, as a rule, did not wear shoes, their bare feet were continually subjected to contamination from fallout on the ground.

11.150 During the first 24 to 48 hours, a number of individuals in the more highly contaminated groups experienced itching and a burning sensation of the skin. These symptoms were less marked among those who were less contaminated with early fallout. Within a day or two all skin symptoms subsided and disappeared, but after the lapse of about 2 to 3 weeks, epilation and skin lesions were apparent on the areas of the body which had been contaminated by fallout particles. There was apparently no erythema, either in the early stages (primary) or later (secondary), as might have been expected, but this may have been obscured by the natural coloration of the skin.

11.151 The first evidence of skin damage was increased pigmentation, in the form of dark colored patches and raised areas (macules, papules, and raised plaques). These lesions developed on the exposed parts of the body not protected by clothing, and occurred usually in the following order: scalp (with epilation), neck, shoulders, depressions in the forearm, feet, limbs, and trunk. Epilation and lesions of the scalp, neck, and foot were most frequently observed (Figs. 11.151 a and b).

11.152 In addition, a bluish-brown pigmentation of the fingernails was very common among the Marshallese and also among American Negroes. The phenomenon appears to be a radiation response peculiar to the dark-skinned races, since it was not apparent in any of the white Americans who were exposed at the same time. The nail pigmentation occurred in a number of individuals who did not have skin lesions. It is probable that this was caused by gamma rays, rather than by beta particles, as the same effect has been observed in dark-skinned patients undergoing X-ray treatment in clinical practice.

11.153 Most of the lesions were superficial without blistering. Microscopic examination at 3 to 6 weeks showed that the damage

Figure 11.151a. Beta burn on neck 1 month after exposure.

was most marked in the outer layers of the skin (epidermis), whereas damage to the deeper tissue was much less severe. This is consistent with the short range of beta particles in animal tissue. After formation of dry scab, the lesions healed rapidly leaving a central depigmented area, surrounded by an irregular zone of increased pigmentation. Normal pigmentation gradually spread outward in the course of a few weeks.

11.154 Individuals who had been more highly contaminated developed deeper lesions, usually on the feet or neck, accompanied by mild burning, itching, and pain. These lesions were wet, weeping, and ulcerated, becoming covered by a hard, dry scab; however, the majority healed readily with the regular treatment generally employed for other skin lesions not connected with radiation. Abnormal pigmentation effects persisted for some time, and in several cases about a year elapsed before the normal (darkish) skin coloration was restored (Figs. 11.154 a and b).

11.155 Regrowth of hair, of the usual color (in contrast to the skin pigmentation) and texture, began about 9 weeks after contamination and was complete in 6 months. By the same time, nail discoloration had grown out in all but a few individuals. Seven years later, there were only 10 cases which continued to show any effects of beta burns, and there was no evidence of malignant changes.

CHAPTER XII

PRINCIPLES OF PROTECTION

BASIS FOR PROTECTIVE ACTION

INTRODUCTION

12.01 In the preceding chapters the phenomena and the destructive effects of nuclear explosions have been described in terms that are reasonably exact. In addition, the best available assessment of these effects on man have been presented. But in planning protection from the consequences of a nuclear explosion, so many uncertainties are encountered that precise analysis of a particular situation is impractical. For example, it is impossible to know in advance where or when a weapon will be detonated and what will be the explosive energy or the kind of burst. Nevertheless, there are some basic principles which, if properly understood and applied, could provide a measure of protection to a large proportion of the population in the event of a nuclear attack.

12.02 The most fruitful application of the principles of protection requires considerable preplanning on the part of individuals; however, some protection may be possible even in certain emergency situations if the principles are understood beforehand. It is the purpose of this chapter to present the quantitative aspects of weapons effects in a simplified form and to use them to explain the principles of protection. The information provided should be helpful in indicating the nature of the protection required and what steps must be taken in advance to achieve such protection. However, details of specific measures are not included since they are described in other publications.[1]

12.03 In the following sections the various effects of a nuclear explosion will be reviewed, with special reference to their ranges, and the principles of protection against each of these effects will be examined. At the same time, it will be shown how the measures used to provide protection from one particular effect can furnish protection against

[1] See the bibliography at the end of the chapter.

722-454 O - 64 - 41

others, so that the problem is less complicated than it might at first appear. Finally, a brief discussion will be presented of the planning needed to implement the principles of protection so as to make them effective.

Immediate and Delayed Effects

12.04 The effects of a nuclear explosion may be divided into two broad categories, namely, immediate and delayed. The immediate effects are those which occur within a few minutes of the actual explosion. These include air blast and ground shock, thermal radiation (light and heat), and initial nuclear radiation.

12.05 The delayed effects are associated with the radioactivity present in fallout and neutron-induced radioactivity. The early fallout from a surface burst will begin to reach the ground within a few minutes after the explosion at close-in locations, and at increasingly later times at greater distances from ground zero, depending on the effective wind speed and direction. At distances of several hundred miles from the explosion, the fallout may not commence until as late as 24 hours after the burst time. Furthermore, several hours may elapse between the time of arrival of the fallout at any point and the time when deposition is essentially complete. A significant early fallout is associated with a surface burst or a subsurface burst which vents to the atmosphere, but not with an air burst or with a completely contained underground burst. Neutron-induced radioactivity, apart from that in the weapons residues, extends only a short distance from ground zero and it decays more rapidly than fallout.

12.06 Except for a contained burst, all presently known nuclear weapons produce delayed (world-wide) fallout. However, this part of the fallout is generally not apparent until several weeks or months have elapsed; it will not be treated here, since the present discussion refers to protection which is effective at the time of, and soon after, an explosion.

Ranges of Various Immediate Effects

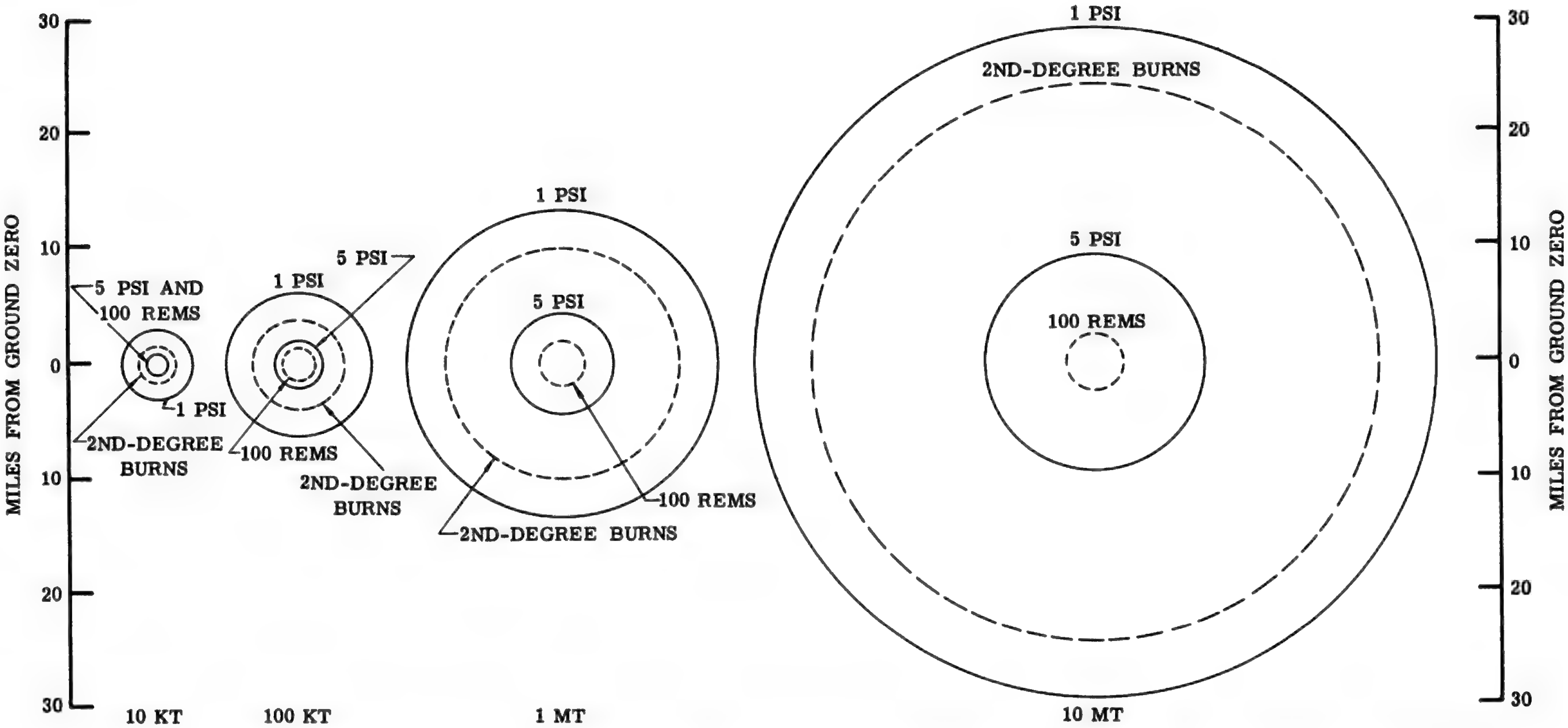
12.07 When a nuclear weapon of known yield is detonated on the surface, at a particular height in the air, or at a particular depth below the surface, the ranges of the immediate effects are fairly well defined. For example, there will be an area surrounding ground zero within which the destruction due to blast and shock, and accompanying fires, will be so great that the survival of inhabitants in conventional structures is improbable. At considerably greater distances the immediate

effects will be weaker and damage to structures will be minor, e.g., broken windows and damage to window frames and doors. The radiation from fallout may be significant in this region, but this is a delayed effect which will be considered later (§12.48 *et seq.*). Between the zone of total destruction and the area at which damage is not significant, there is a region in which protective measures can determine whether inhabitants survive, with little or no injury, or whether they become serious casualties.

12.08 The distances from ground zero within which various degrees of destruction may be expected depend primarily upon the energy yield of the explosion and the conditions of the burst, i.e., air, surface, etc. The topography and weather also influence these distances. By using the data presented in the earlier chapters, it is possible to draw a series of circles, as depicted in Fig. 12.08, representing areas within which effects of different types are to be expected for air bursts of various yields from 10 kilotons to 10 megatons TNT equivalent. The height of burst is such as to maximize the distance to which each effect extends; in other words, the radii of the circles give the greatest ranges at which the indicated thermal radiation, initial nuclear radiation, and overpressure levels will occur for any air burst of the given energy yield. It should be mentioned that the circular areas depict an idealized situation. Actually, as was the case in Japan, the pattern would be distorted by the conditions of the terrain, weather, etc. Two or more weapons detonated within a short distance can, of course, change the situation considerably.

12.09 Within the ring at which the blast overpressure is 5 pounds per square inch (5 psi), nearly all conventional houses will be damaged beyond repair. Even strong buildings, such as reinforced concrete and steel structures, will suffer damage and, without protective measures, the casualties to the inhabitants of this area will be high. In the central zone of heavy damage, there will alsa be a great fire hazard. Individuals in this area will be exposed not only to the effects of blast, but also to nuclear and thermal radiation. Apart from fortuitous circumstances, few persons will survive who have not sought protection in strong structures or shelters which will withstand the fire, blast, and shock and which will attenuate the radiation.

12.10 At distances from the burst where the blast overpreseure is 1 psi, the destructive effect of the air blast wave is minor. Window frames, doors, and plaster will suffer light damage. Window panes will be broken at much greater distances. The initial nuclear radiation dose will be so small that its immediate consequences are negligible, but thermal radiation may still be a significant source of



Idealized ranges for effects of air burst with the heights of burst optimized to give the maximum range for each effect

casualties. Second-degree burns may be experienced at distances approaching those for 1 psi overpressure and less severe burns may be suffered at much greater distances from ground zero. Eye injury may also occur at even greater ranges and for high-altitude bursts of megaton weapons, this distance may be as much as several hundred miles. Furthermore, in dry, clear weather, many small fires would probably be ignited in newspapers and other thin combustible materials both within and outside of buildings.

Effective Protection Areas

12.11 In Japan, where little evasive action was taken, the survival probability depended upon whether the individual was outdoors or inside a building and, in the latter case, upon the type of structure. At distances between 0.3 and 0.4 mile (530 and 700 yards) from ground zero in Hiroshima the average survival rate, for at least 20 days after the nuclear explosion, was less than 20 percent. Yet in two reinforced-concrete office buildings, at these distances, almost 90 percent of the nearly 800 occupants survived more than 20 days, although some died later from radiation injury. Furthermore, of approximately 3,000 school students who were in the open and unshielded within a mile of ground zero at Hiroshima, about 90 percent were dead or missing after the explosion. But of nearly 5,000 students in the same zone who were shielded in one way or another, only 26 percent were fatalities. These facts bring out clearly the greatly improved chances of survival from a nuclear explosion that could result from the adoption of suitable warning and protective measures.

12.12 As a rough guide, the inner range at which protection in conventional structures could be achieved may be supposed to be that where the overpressure is 5 pounds per square inch and the outer range, beyond which casualties will be small *for an air burst*, is at 1 pound per square inch (or the limit for second-degree burns). As seen above, survival in Hiroshima was possible in buildings at such distances that the overpressure in the open was 15 to 20 pounds per square inch. The somewhat arbitrary choice of an overpressure of 5 pounds per square inch, which was experienced at a little over a mile from ground zero in Japan, is thus very conservative. In any case, it is evident from the circles in Fig. 12.08 that the area over which protection could be effective in saving lives is roughly eight to ten times as great as that in which the chances of survival are small. It may be concluded, therefore, that a considerable proportion of the population "at risk" from a nuclear explosion would be in an area in

12.17 The time sequence referred to in § 12.16 brings up another aspect of nuclear weapons effects that has a bearing on protection. Except very close to ground zero, even the immediate effects do not occur simultaneously. The first, almost instantaneous, indication of a nuclear explosion in the air or on the earth's surface is a brilliant flash of light. In many circumstances, it may be feasible, after observing the flash, to take some appropriate protective action that could greatly minimize the degree of injury suffered. At distances beyond those at which the immediate blast, thermal, and initial nuclear effects of the explosion are significant, there may be some time to make final preparations to decrease the early fallout.

12.18 As a general guide for planning purposes, it is useful to know the magnitudes of the respective immediate effects at a range of distances from an explosion of given yield. This information can be obtained from various figures and tables given in earlier chapters and can be identified from the list in the table of contents at the beginning of the book. A tabular summary of part of the data for air bursts, which may be more convenient for some purposes, is given in Table 12.18. The heights of burst are such as to maximize the various effects. An asterisk indicates that the particular distance is within the fireball; otherwise a blank space implies that the value is too small to be significant. The initial nuclear radiation doses are not given for distances of 5 miles or more for they are extremely small even for a 10-megaton explosion.

BLAST EFFECTS

Effects on Structures

12.19 Injury to individuals both inside and outside a structure may occur because of the blast damage to that structure. Persons in the interior of the building can be injured and trapped by collapse and fire, and those outside can be hurt by flying debris. For these and other reasons, an important aspect of protection is an understanding of the relative ability of different structures to withstand damage from air blast. Both the peak overpressure and the peak dynamic (or wind) pressure determine the amount of the damage, but for certain structures one or the other of these pressures has the dominant effect. For most office-type and residential buildings, including ordinary houses, the extent of destruction is mainly dependent on the peak overpressure, and an approximate correlation between the overpressure and the expected physical damage is given in Table 12.19.

TABLE 12.29—ARRIVAL TIME FOR PEAK OVERPRESSURE

Distance (miles)	Explosion yield				
	1 KT	10 KT	100 KT	1 MT	10 MT
	(Time in seconds)				
1	4. 3	3. 6	3. 7	2. 5	1. 5
2	>9	8. 1	7. 4	6. 5	5. 0
3	--------	>13	12	11	9. 5
5	--------	--------	21	20	16
7	--------	--------	>30	28	26
10	--------	--------	--------	42	37
20	--------	--------	--------	>90	83
30	--------	--------	--------	--------	>130

12.30 It is seen that at 10 miles from a 10-megaton air burst, which is within the area where protection against blast could be effective, some 37 seconds would elapse before arrival of the blast wave. If prompt action is taken, a person in a building could reach a position of the type indicated above. In the open, some protection against the blast may be obtained by falling prone, and remaining in that position until the wave has passed. In the prone position, with the head directly toward or directly away from the explosion, the area of the body exposed to the onrushing blast wave is relatively small and the danger of displacement is thereby decreased (cf. § 11.38).

THERMAL RADIATION EFFECTS

EFFECTS ON PERSONNEL

12.31 The main direct effects of thermal radiation on human beings are skin burns, generally called flash burns to distinguish them from flame burns, and permanent or temporary eye damage. Burns are classified by "degree"; first-degree burns being mild in nature, roughly similar to moderate sunburn; they should heal without special treatment. Second-degree burns are associated with blister formation and if a significant area of the body is involved, medical attention is necessary (§ 11.44 *et seq.*). The approximate limiting distances from air bursts of various total yields at which first- and second-degree burns of exposed (light-colored) skin may be expected are given in Table 12.31. Third-degree burns, which involve the entire thickness of the skin, can occur at shorter ranges. For a surface burst, the respective distances are decreased to about four-fifths of the values in the table. The ranges shown are actually from the burst point

rather than from ground zero, but at the heights of burst that maximize the distances over which burns are experienced, the differences are small.

TABLE 12.31

RANGES FROM GROUND ZERO FOR BURNS TO BARE SKIN FROM AIR BURSTS*

	Explosion yield				
	1 KT	*10 KT*	*100 KT*	*1 MT*	*10 MT*
	(Distance in miles)				
First-degree burn	0.7	1.9	5.3	14	>30
Second-degree burn	0.5	1.5	4.0	11	24

*For a surface burst the distances are about four-fifths those for an air burst of the same yield.

12.32 The data presented in Table 12.31 are applicable to reasonably clear atmospheric conditions. Fog or mist near the ground or a layer of cloud between the point of the explosion and the ground would attenuate the thermal radiation and thus decrease the ranges at which flash burns may be experienced by exposed persons. However, snow on the ground or cloud layers above the explosion provide reflecting surfaces which increase these ranges.

12.33 Eye injuries are of two main types: temporary (flash blindness) and permanent (chorioretinal burns), as described in § 11.69 *et seq.* Both kinds of injury can occur at great distances from the explosion, considerably greater even than those for first-degree burns given in Table 12.31. The nature and extent of the eye injury depends on the yield and type of burst, on the orientation of the observer to the burst, on the clarity of the atmosphere, and on the size of the pupil opening. As a general rule, permanent eye injury would be expected only in those persons who were looking directly at the fireball. Flash blindness, on the other hand, could be quite general over a large area.

PROTECTIVE MEASURES

12.34 In an air or surface burst, the thermal radiation is received in two pulses, in each of which there is a maximum of intensity followed by a decrease. If an individual is caught in the open or is near a window in a building at the time of a nuclear explosion, evasive action to minimize flash burn injury should be taken, if possible, before the maximum in the second pulse. At this time only 20 percent of the thermal energy will have been received, so that a large proportion can be avoided if shelter is obtained before or soon after

the second thermal maximum. The elapsed times between the instant of the explosion and the second thermal maximum for air and surface bursts of various energy yields are recorded in Table 12.34. From this table it is seen that the prospects of being able to take evasive action are not good for air or surface bursts of low energy yield, but some possibility may exist for explosions in the megaton range.

TABLE 12.34

TIME TO SECOND THERMAL MAXIMUM

	Explosion yield				
	1 KT	*10 KT*	*100 KT*	*1 MT*	*10 MT*
Time (seconds)	0. 03	0. 1	0. 3	1. 0	3. 2

12.35. The major part of the thermal radiation travels in straight lines, and so any opaque object interposed between the fireball and the exposed skin will give some protection. This is true even if the object is subsequently destroyed by the blast, since the main thermal radiation pulse is over before the arrival of the blast wave.

12.36 At the first indication of a nuclear explosion, by a sudden increase in the general illumination, a person inside a building should immediately fall prone, as described in § 12.30, and, if possible, crawl behind or beneath a table or desk or to a planned vantage point. Even if this action is not taken soon enough to reduce the thermal radiation exposure greatly, it will minimize the displacement effect of the blast wave and provide a partial shield against splintered glass and other flying debris. An individual caught in the open should fall prone to the ground in the same way, while making an effort to shade exposed parts of the body. Getting behind a tree, building, fence, ditch, bank, or any structure which prevents a direct line of sight between the person and the fireball, if possible, will give a major degree of protection. If no substantial object is at hand, the clothed parts of the body should be used to shield parts which are exposed. There will still be some hazard from scattered thermal radiation, especially from high-yield weapons at long range, but the decrease in the direct radiation will be substantial.

12.37 Clothing of the proper kind provides good protection against flash burns. Materials of light color are usually preferable to dark materials because the former reflect the radiation. Clothing of dark shades absorbs the thermal radiation and may become hot enough to ignite, so that severe flame burns, which are more serious that the flash burns, may result. Woolen materials give better protection than those of cotton of the same color, and the heavier the fabric the

greater the protection. An air space between two layers of clothing is very effective in reducing the danger of flash burns.

12.38 Protection against eye injury is difficult, especially for those persons who happen to be facing the burst point. The blink reflex, i.e., the automatic blinking of the eye, which requires 0.15 second, may be helpful in providing some protection from air and surface bursts in the megaton range. It is doubtful, however, if much can be done at those distances where the same total amount of thermal energy is received from weapons of lower energy. In a nuclear explosion at high altitude, that is, at heights above 20 miles, the thermal radiation is emitted in a single rapid pulse. Assuming the total thermal energy received by a person at a particular location is sufficient to cause flash burns or eye injury, it seems improbable that any evasive action will be effective, as even the involuntary blink will not be in time to help very much. Ordinary sunglasses will provide little or no protection against eye damage, since much more opaque material would be required to decrease the radiation intensity. In all cases individuals should make every effort to avoid looking toward the fireball.

Fire Protection

12.39 After a nuclear attack on an urban area, extensive fires may develop as they did in Japan. Such fires were started both directly by thermal radiation and by secondary blast effects, i.e., overturning of stoves, short circuiting of electrical wires, etc. (§ 7.69). Appropriate fire control action may be directed along three lines, namely, (1) reduction of potential ignition points, (2) provision for isolation or rapid extinction of ignitions to prevent formation of large fires, and (3) minimization of the consequences should large-scale fires develop.

12.40 Since the elimination of wood as a construction material for houses is virtually impossible, potential ignition points can be decreased by continuous upkeep of existing wood structures and by taking steps to keep yards free from all combustible trash. As stated in § 7.57 *et seq.*, it was clearly demonstrated at the 1953 tests in Nevada that a well-maintained house, with a yard free from trash, is much more capable of withstanding the thermal effects of a nuclear explosion than is a poorly-maintained house or one with an unkept yard. Fire-resistive furnishings, e.g., draperies, rugs, etc., made of vinyl plastic or wool, also proved to be advantageous in these tests.

12.41 The second aspect of fire control action is to plan and train for the elimination of small fires before they can grow into serious ones.

In Japan the fires were so numerous and spread so rapidly that it would have been beyond the capability of regular fire departments to deal with them even if the latter had survived the bombings. The training of private individuals in emergency methods of firefighting, such as were developed in Europe during World War II, is therefore desirable. By extinguishing small fires soon enough, the number of serious fires may be sufficiently small to be dealt with by professional firefighters.

12.42 Conventional methods for preventing the spread of large fires, by the use of natural and artificial fire breaks, were not too successful in Japan, for the reasons mentioned in § 7.72. Nevertheless, consideration should be given to the provision of adequate fire breaks and to the zoning and planning of urban areas. As seen in § 7.55, the potential for the development and spread of fires is greatest in wholesale distribution and slum residential areas. Dispersal and protection of utilities and emergency services should be included in such planning.

INITIAL NUCLEAR RADIATION

Effects on Personnel

12.43 The initial nuclear radiation consists of gamma rays and neutrons received during the first minute after the explosion. Doses of this radiation up to 100 rems, over the whole body, would have little or no immediate observable effects on exposed individuals. The only effect expected might be a slight feeling of fatigue in some people. Many persons receiving larger doses, up to 200 rems, would not be greatly affected by the radiation, except for blood changes. For the present purpose, however, it will be supposed that a whole-body dose of 100 rems will cause few, if any, casualties requiring medical attention. At the other extreme, it is probable that every person receiving 1,000 rems over the whole body will become sick within 4 hours (or less) of exposure and will die in 2 or 3 weeks. Between these extremes there is a great deal of variation in the expected effects on personnel, but at an exposure of around 400 to 500 rems, all will be nauseated and vomit on the first day, and most will require medical care. However at this exposure, at least one-half of the people will probably recover.

12.44 The actual distances from air bursts of various yields at which the initial nuclear radiation will produce doses of 100, 500, and 1,000 rems, respectively, to completely unprotected individuals are

shown in Table 12.44. However, the heights of burst which maximize these distances are such that the latter are not very different from the ground zero ranges. For purposes of comparison, the distances for an overpressure of 5 pounds per square inch and for second-degree flash burns of exposed skin are included. It is seen that the hazards from blast and thermal radiation extend to much greater distances than do those from initial nuclear radiation, especially for weapons of yields in excess of 10 kilotons. For example, an individual 2 miles from a 1-megaton burst probably would show no significant symptoms of nuclear radiation sickness, but the thermal radiation exposure would be 210 calories per square centimeter (see Table 12.18). Less than 7 calories per square centimeter are sufficient to produce a second-degree skin burn from an explosion of 1 megaton. The corresponding blast wave overpressure of 18 pounds per square inch would cause severe damage to the strongest conventional structures (cf. Table 12.19).

TABLE 12.44

RANGES FROM GROUND ZERO FOR VARIOUS INITIAL NUCLEAR RADIATION DOSES FROM AIR BURSTS*

	Explosion yield				
	1 KT	*10 KT*	*100 KT*	*1 MT*	*10 MT*
	(Distances in miles)				
Radiation Dose					
100 rems	0. 7	1. 0	1. 3	1. 8	2. 4
500 rems	0. 6	0. 8	1. 1	1. 5	2. 1
1,000 rems	0. 5	0. 7	1. 0	1. 4	2. 0
Other Effects					
5 psi	0. 4	0. 9	2. 0	4. 3	9. 2
Second-degree burns	0. 5	1. 5	4. 0	11	22

*The distances for a specified radiation dose are slightly less for a surface burst.

PROTECTION FROM INITIAL NUCLEAR RADIATION

12.45 It is apparent that for weapons with yields greater than 10 kilotons, the regions in which large doses of initial nuclear radiation could be received are those of high blast pressure and intense thermal radiation. Protection against all three effects would be provided by a massive reinforced, fire-resistant building. An 18-inch thickness of concrete, for example, would reduce the fatal dose of 1,000 rems to the tolerable one of about 100 rems. Thus, aboveground buildings of massive construction would provide some protection against the initial nuclear radiation. Additional protection may be obtained in basements beneath substantial concrete floor slabs. The surrounding

earth also helps in this connection; a 26-inch thickness of earth attenuates the radiation by a factor of about ten and 3 feet by about thirty.

12.46 The immediate evasive action suggested earlier for limiting the effects of thermal radiation and blast to a person in the open may assist, to a lesser extent, in reducing the dose of initial nuclear radiation. From high-yield weapons, in particular, a second or two elapses before much of the nuclear radiation is delivered at distances where survival is possible (§ 8.43). Table 12.46 gives the percentage of the total initial gamma-radiation dose received at given distances from 20-kiloton and 5-megaton explosions as a function of time. The total unshielded dose would be about 4,500 roentgens in each case.

TABLE 12.46

INITIAL GAMMA-RADIATION DOSE AS A FUNCTION OF TIME

		Time (seconds)						
		1	*2*	*4*	*7*	*10*	*15*	*20*
Explosion yield	*Distance (miles)*	*Percentage of initial gamma-radiation dose delivered*						
20 KT	0. 5	67	78	88	95	97	100	-----
5 MT	1. 5	5	17	43	76	90	98	100

12.47 As shown by the table, there is some possibility of reducing the radiation dose by immediate evasive action. However, from the numbers given above for the attenuation by concrete and earth, it is obvious that a nuclear radiation shield must be very massive if it is to be effective. Normal clothing, for example, will do little to attenuate initial nuclear radiation, although it may provide complete protection from thermal radiation. Another difficulty in connection with obtaining shelter in the open is the scattering of nuclear radiation, so that it may reach a person from many directions and not just along a direct line from the point of explosion.

RESIDUAL NUCLEAR RADIATION

Fallout Hazard

12.48 The principal effects on personnel from residual radiation are similar to those from comparable doses of initial nuclear radiation as described in the preceding section. However, the hazards of exposure to residual radiation are entirely different from exposure to initial radiation and these hazards are described in this section.

12.49 Protection against residual nuclear radiation occupies a position of special significance. Because the early fallout can cover

an area much larger than that over which blast, thermal radiation, and initial nuclear radiation are significant, it is possible for people to become casualties at such distances from the explosion that the immediate effects are negligible or completely absent. As noted earlier, it is not feasible to state the degree of hazard from residual radiation in a reasonably accurate manner because it is so highly dependent upon conditions, especially wind speeds and directions over a considerable height. It is certain, however, that a surface burst in the megaton range will lead to contamination of very large areas by early fallout. This fallout will reach the ground very soon after the explosion at near distances, but at distances of several hundred miles, up to 24 hours may elapse before the fallout starts to arrive.

12.50 The early fallout hazard is of two main kinds: one results from the actual contact of the radioactive material with the skin, causing what are called "beta burns" produced by the action of the beta particles, and the second is due to the continuous exposure of the body to gamma rays, both direct and scattered, from fallout particles. It is with the second of these hazards that the discussion here will be mainly concerned. The protective measures for use against beta burns are chiefly associated with keeping the dust-like particles off the skin. If the fallout dust does get on the skin, it should be immediately washed off with soap and water. The possible hazard from entry of radioactive material into the body by ingestion will be considered later (§ 12.66 *et seq.*).

Induced Radioactivity

12.51 In addition to the radioactive fallout, there may be a residual radiation hazard near ground zero caused by induced activity resulting from the capture of neutrons by various elements in the soil, especially sodium and manganese. The induced-activity hazard may exist on the ground after an air burst when the initial fallout is virtually absent. However, this activity not only decays much more rapidly than does that from fallout, but it extends only a short distance (1 mile or less) from ground zero. Since the destruction in this area would be considerable, the only persons entering it for some time after the explosion should be rescue teams and others performing urgent missions. Such teams would be equipped with instruments to inform them of the radiation hazard.

Protective Measures

12.52 Assuming the population is to remain in the fallout area, and not be evacuated, it is necessary to obtain protection which

attenuates the gamma radiation. The basic principle to be borne in mind is that any massive or thick material will decrease the nuclear radiation level to some extent, whereas lighter construction, e.g., window areas, hollow, thin, or light walls, etc., permits the radiation to penetrate. A layer of concrete 8 inches thick or of earth 12 inches thick will yield an attenuation factor of 10; [2] doubling these thicknesses will increase the factor to 100. Thus, each extra foot of earth between an individual and the fallout will increase the protection factor tenfold. It should be remembered that scattered radiation will come from many directions, and so protection is necessary from all directions, either by the use of a mass of material or by distance.

12.53 Information has been published that describes procedures and standards for evaluating the potential of existing structures as fallout shelters and for modifying such structures to improve their effectiveness in this respect. The recommended procedures and standards may also be utilized in the design of new structures. Furthermore, instructions for building simple and effective fallout shelters are readily available. Basically, a fallout shelter is a structure with massive walls and ceiling. Practical materials of construction are earth, concrete, or solid masonry. Attenuation of the gamma radiation is provided by absorption in these materials and by the distance separating the fallout particles from the people in the shelter.

12.54 Since a shelter may have to be occupied continuously for periods as long as 2 weeks, until the natural decay of the radioactivity outside will allow the people to emerge, stocks of food and other supplies will be required. Where fallout arrives soon after the explosion, the early radiation dose rate will be high. It may then be necessary to wait several days before it is possible to come out of the shelter for more than a limited period without risking a radiation dose of sufficient magnitude to cause serious illness. In the path of the fallout, the early radiation levels will be lower at more distant points from the explosion, and the time necessary to occupy the shelter will be shorter, unless "hot spots" are present (§ 9.55). However, in any area where contamination is at all significant, it will probably be necessary to spend the first day or two after the burst sheltered from the residual gamma radiation. It is during the period immediately following the nuclear explosion, when the radiation level is at its highest, that protection is most important.

---

[2] It should be noted that more than twice these thicknesses of concrete (18 inches) and of earth (26 inches) are required to attenuate the initial nuclear radiation to the same extent (§ 12.45) because the energy of the initial gamma rays is greater than in the residual (fallout) radiation.

12.55 A fallout shelter of the kind referred to in § 12.53 will provide a protection factor of about 200 from the residual radioactivity; in other words, the dose rate in the shelter will be only ½ percent of that measured outside at a height of 3 feet above the ground. Where a shelter is not available, a similar protection factor from radiation can be obtained in the following manner in a small area of the basement of a two-story house. A sturdy table is placed in a corner adjacent to an unexposed outer wall and covered with 10 to 12 inches of soil, sandbags, solid concrete block, etc., according to what is available. If there are no heavy partitions or walls near the corner of the basement chosen, a layer of sandbags or concrete blocks should be stacked along the walls up to the height of the material on top of the table. Within the area under the table, there will be a protective factor of at least 100 from fallout radiation. The disadvantage of this type of protection is that it is unlikely that stocks of food and water would be available within the shelter, so that it could not be occupied continuously for an extended period, as could the more permanent type outlined previously. In almost any house with a buried basement, having uniformly thick exterior walls, a protection factor of 20 to 40 is possible. The maximum protection can be obtained near the floor and in the corners of the basement adjacent to an unexposed outer wall.

12.56 Before leaving a shelter, either temporarily or permanently, it is highly desirable that the radiation dose rate, both in the immediate area of the shelter and in the surrounding vicinity, be known. Marked variations in fallout patterns have been observed in weapons tests, with unexpected areas (hot spots) of exceptionally high activity. Hence, it is not sufficient to know merely that a nearby location is relatively safe. Communications equipment, e.g., battery-powered radios, and radiation measuring instruments should be in shelters. Otherwise it will not be possible to obtain information on radiation dose rates in the locality and in the immediate vicinity of the shelter, particularly at early times when high radiation levels will prevent radiation monitors from moving safely and freely about the community. As a rough rule-of-thumb, it may be stated that for every sevenfold increase in time, the radiation level will decrease by a factor of 10, provided the fallout is complete. For example, the radiation level at the end of 7 days will have fallen to roughly one-tenth of that at the end of 1 day. At the end of 49 days, it will have decreased by a factor of 100, etc.[3]

12.57 It is appropriate to mention here that whether or not fallout is visible to the eye, its measurement requires the use of suitable

[3] The rule is applicable to any unit of time; thus at 7 hours the residual radiation level will be one-tenth of that at 1 hour, at 14 hours it will be one-tenth of that at 2 hours, and so on, provided the fallout is complete at both times.

instruments sensitive to nuclear radiations. Some, although perhaps not all, of the fallout in the Marshall Islands, after the test explosion of March 1, 1954 (§ 9.100 *et seq.*), could be seen as a white powder or dust. This was due, partly at least, to the light color of the calcium oxide or carbonate of which the particles were mainly composed. It is probable that whenever there is sufficient fallout to constitute a hazard, the dust will be visible. Nevertheless, continuous monitoring with instruments for radioactive contamination would appear to be essential in all areas in the vicinity of the burst.

Radiological Surveys

12.58 As soon after a nuclear explosion as conditions permit, radiological monitoring surveys will have to be initiated for the purpose of developing information on the extent and levels of the contamination. At early times in heavily contaminated areas, where dose rates will be very high, only the most limited amount of monitoring can be accomplished by individuals with hand-carried instruments. In these circumstances, some kind of remote radiation monitoring equipment may be necessary. This will permit the monitor to remain within the shelter while taking readings of the dose rate outside.

12.59 The most rapid method for obtaining radiation levels in a large area is by aerial survey. Because of their long range in air, gamma rays can be detected by sensitive instruments at a height of a few thousand feet. Low-flying airplanes or helicopters, carrying suitable radiation instruments for measuring dose rates, can survey large areas unimpeded by damage on the surface and by impassable streets and roads. Moreover, by making initial flights at an altitude of 1,600 feet or so, the dose rates are only about 1 percent of those on the ground, so that the hazard to the monitor is decreased accordingly.

12.60 The dose rates measured at an altitude must be multipled by an appropriate factor to give the approximate dose rates near the ground. This factor will depend primarily on the height above the ground and nature of the terrain. In the absence of more specific information, the data in Fig. 9.181 may be used to estimate the attenuation factor at a known altitude with reference to that at a height 3 feet above the ground.

12.61 The aerial survey is important because it can be made readily and can provide information which might be impossible to obtain in any other way at the time of interest. Nevertheless, such a survey can serve only as a rough guide and should be made only after all the early fallout is out of the air and on the ground. For points of special

The allowable dose (D) is divided by the dose rate (R) at the time of entry to give D/R, i.e., $25/45=0.55$. This result falls between two values in the left-hand column of Table 12.64, and the smaller one is taken. Follow the $D/R=0.5$ line horizontally until the column headed "8 hours" after the detonation is reached. The allowable stay time is seen to be 31 minutes; for $D/R=0.6$, the corresponding time is 38 minutes, and so the actual permissible stay time would be about 34 minutes. By using both Tables 12.63 and 12.64, a variety of other estimates can be made.

12.65 There are two important reservations which must be kept in mind in using Tables 12.63 and 12.64. First, if there is any change in the situation, either by further contamination or by decontamination in the period between the two times concerned, the results will not be valid. Second, even if the conditions under which the tables are applicable are fulfilled, the estimates should be used for *planning purposes only*, and to provide a guide for any action that may be required. Changes in dose rates and total accumulated doses over a period of time must always be checked by instruments.

Food and Water

12.66 After a nuclear attack, in addition to protection from external residual radiation exposure, it is important that personnel in the fallout area also be protected from internal radiation exposure due to ingestion of radioactive fallout material along with food and water. Food and water are not adversely affected by exposure to the residual radioactivity. The principle of protection to be understood is that fallout material must be removed from food and water prior to consumption to prevent this material from getting inside the body. Relative to that which could be taken into the body by eating and drinking, it appears that the amount of radioactive material taken in by inhalation may be small (see §11.160). Nevertheless, air which contains fallout particles should not be directly inhaled without a protective respiratory device (such as a dust-filter respirator) until it is established by monitoring procedures that the air is free from radioactive contamination.

12.67 The contamination of emergency food and water supplies by residual radiation can be prevented by storing them in dust-tight containers. Although the outside of a container may become contaminated by fallout, most of the radioactive substance can be removed by washing the container before it is opened. The foods or

fluids can then be removed and consumed without significant contamination.

12.68 If emergency food supplies do become contaminated, or if it is necessary to resort to contaminated sources after emergency supplies are exhausted, many types of food can be treated to remove the radioactive material. Fresh fruits and vegetables can be washed or peeled to remove the outer skin or leaves. Food products of the absorbent type cannot be decontaminated in this manner and should be disposed of by burial. Boiling or cooking of the food has no effect in removing the fallout material. Milk, from cows which survive in a heavily contaminated area, may not be safe to drink because of the radioiodine content and this condition may persist for weeks or months.

12.69 Domestic water supplies from underground sources will usually remain free from radioactive contamination. Water supplies from surface sources may become contaminated if watersheds and open reservoirs are in areas of heavy fallout. However, most of the radioactive fallout material would be removed by regular water treatment which includes coagulation, sedimentation, and filtration. If a surface water supply is not treated in this manner, but merely chlorinated, it may be unfit for consumption for several days after an attack. As a result of dilution and natural decay the contamination will decrease with time.

12.70 If the regular water supply is not usually subjected to any treatment other than chlorination, and an alternative source is not available, consideration should be given in advance planning to the provision of ion-exchange columns or beds for emergency decontamination use. Home water softeners might serve the same purpose on a small scale. The water contained in a residential hot-water heater would serve as an emergency supply, provided it can be removed without admitting contaminated water. Water may also be distilled to make it safe for drinking purposes. *It should be emphasized that mere boiling of water contaminated with fallout is of absolutely no value in removal of the radioactivity.*

Decontamination

12.71 Decontamination is the process of removing radioactive material from a location where it is a hazard to one in which it can do little or no harm. It is one of the means which are available for reducing the radiation dose that would be received from fallout. Pref-

erably it should be accomplished under the supervision of personnel trained in decontamination procedures. Radiation measuring instruments should be used not only to determine the effectiveness of the decontamination but also to make sure that the contaminated material is disposed of in a safe manner.

12.72 Because of its particulate nature, fallout will tend to collect on horizontal surfaces, e.g., roofs, streets, tops of vehicles, and the ground. In the preliminary decontamination, therefore, the main effort should be directed toward cleaning such surfaces. The simplest way of achieving this is by water washing, if an adequate supply of water is available. The addition of a commercial wetting agent (detergent) will make the washing more efficient. The radioactive material is thus tranferred to storm sewers where it is less of a hazard. Covering the ground around a building with uncontaminated earth or removing the top layer of the ground to a distance, by means of earth-moving equipment, are methods for reducing the dose rate inside a building. Inasmuch as decontamination of streets, buildings, and other large items requires substantial manpower and resources, the effectiveness of these operations will benefit from sound planning and skilled supervision.

12.73 It is important to note, in connection with removal of contaminated earth for the purpose described above or to provide a means of transit, that the gamma rays from fission products can travel considerable distances through air. For example, at 3 feet above the ground, roughly 50 percent of the dose rate received in the center of a large, flat, uniformly contaminated area comes from distances greater than 50 feet away, and about 25 percent from distances more than 200 feet away. Thus, complete removal of the contaminated surface from a circle 200 feet in radius would reduce the dose rate in the center to about one-fourth of its original value. However, if the contaminated earth were not completely removed, but just pushed to the outside of the circle, the dose rate would be considerably greater than one-fourth the initial value.

12.74 It is apparent, therefore, that if facilities are to be provided across open country which is contaminated over a large area, bulldozing the top few inches of contaminated soil to the sides will be satisfactory only if a wide strip is cleared. Thus, if the strip is 250 feet in width, the radiation dose rate in the middle will be reduced to one-tenth of the value before clearing. A similar result may be achieved by scraping off the top layer of soil and burying it under fresh soil. Something like a foot of earth cover would be required to decrease the dose rate by a factor of ten.

12.75 Badly contaminated clothing, as well as rugs, curtains, and upholstered furniture, would have to be discarded and buried or stored in an isolated location. When the radioactivity has decayed to a sufficient extent, or if the initial contamination is not too serious, laundering may be effective in reducing the activity of clothing and fabrics, to permit their recovery. Thorough vacuum cleaning of furniture might be adequate in some cases, but an instrument check would be necessary before further use.

SUMMARY

Planning Protection

12.76 In planning protection against the hazards associated with a nuclear attack, it must be recognized that the amount of protection that will be available to individuals is, in a large degree, directly related to the extent of public knowledge concerning nuclear weapons effects and associated protective measures, and to the steps taken prior to the attack to put these measures into a state of readiness. There are certain actions which can be taken by the unprepared in extreme emergencies, but the protection achieved is minor when compared to that which would be available to those who had made adequate preparations. Moreover, following an attack there are certain procedures that can tend to minimize the remaining hazards and these also will be made more effective by sufficient concern beforehand as to their implementation.

12.77 A massive, reinforced, fireproof shelter structure is required at close distances to protect individuals against the severe immediate effects (blast, thermal, and initial nuclear radiation) of a nuclear explosion. This type of protection is the most comprehensive and requires the greatest amount of preplanning effort and knowledge of the effects hazards. Conventional buildings may also be designed to be blast and fire resistant. Measures to minimize the thermal and fire hazard (§ 12.39 *et seq.*) may also be effected. In those areas where early fallout is expected to be a hazard, shelters may be constructed and provision made for occupying them for considerable lengths of time. Knowledge of warning systems and evacuation procedures will also minimize confusion. Moreover, possession of battery operated communications systems and of radiation monitoring equipment will make it possible to obtain information on the condition of the occupied area following an attack.

12.78 In the event that shelters are not available, certain evasive actions may prove helpful at distances where the immediate effects are least severe. By instantly falling prone and covering exposed portions of the body or getting behind opaque objects, much of the thermal radiation may be avoided, especially in the case of large-yield weapons. Under no circumstances should an individual look in the direction of the fireball. Staying behind thick walls or lying in a deep ditch may help to avoid initial nuclear radiation. All of the above actions will also help to decrease the possible danger from the blast wave. Moreover, persons should avoid areas which have frangible materials, such as window glass, plaster, etc., which may become flying debris by the action of the blast.

12.79 After the immediate effects of the nuclear explosion are over, certain acts are required to minimize the hazards of the early fallout and from the fires which may result from thermal radiation and secondary blast effects. First, if small fires can be quickly extinguished, extensive conflagrations may be prevented. This must be accomplished before the arrival of the fallout or in areas of low radioactivity levels. Some protection from the fallout may be secured in the basements of buildings or in a quickly constructed shelter, such as is described in § 12.55. It is important to keep from coming into physical contact with the fallout particles, and to prevent contamination of food and water sources. Monitoring equipment should be used to determine areas which have safe radiation levels and decontamination efforts can proceed to recover necessary equipment, buildings, and areas.

Conclusion

12.80 Much of the discussion presented in earlier sections of this chapter have been based, for simplicity, on the effects of a single weapon. It must not be overlooked that in a nuclear attack some areas may be subjected to several bursts. The basic principles of protection would remain unchanged, but protective action against *all* the effects of a nuclear explosion—blast, thermal radiation, initial nuclear radiation, and fallout—would become even more important. There is a good possibility that many people would survive a nuclear attack and this possibility would be greatly enhanced by utilizing the principles of protection in preattack preparations and planning, in taking evasive action at the time of an attack, and in determining what should be done in the recovery phase after the attack.